THE UNIVERSITY *of* EDINBURGH

The Influence of Carbohydrate Supplementation on Endurance Capacity, Sprint Performance, and Physiological Responses of Adolescent Team Games Players to Prolonged Intermittent High Intensity Exercise

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Declaration

I confirm that the work contained within this thesis is the author's own, that the thesis has been composed solely by the author, and that no aspect of the work has been submitted for any other degree or professional qualification.

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Shaun Martyn Phillips **Date**

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Abstract

Ingesting carbohydrate (CHO) before and during prolonged steady-state exercise can significantly improve the endurance capacity (time to exhaustion) of adolescents. This knowledge, combined with current understanding of the physiological and metabolic responses of young people to prolonged steady-state exercise, as well as awareness of youth team games participation statistics, suggests CHO ingestion before and during team games exercise may be beneficial for adolescent team games players. However, research in this area has not been conducted, presenting a notable gap in the paediatric exercise science literature. This thesis described three studies with the aim of investigating the influence of CHO ingestion immediately before, and during, prolonged intermittent, high-intensity exercise on the endurance capacity, sprint performance, and physiological responses of adolescent team games players. The studies investigated a CHO-electrolyte (CHO-E) solution, solutions of differing CHO concentration ([CHO]), and CHO in the form of a gel in trained 12-14 year old soccer, rugby, and field hockey players during a modified Loughborough Intermittent Shuttle Test (LIST).

Study 1 (n = 15) reported a significant 24.4% enhancement of intermittent endurance capacity with ingestion of a 6% CHO-E solution compared with a placebo (PLA, 5.1 ± 1.8 vs. 4.1 ± 1.6 min, $P < 0.05$, $r = 0.51$), with distance covered also significantly greater in the CHO trial (851 ± 365 vs. 694 ± 278 m, $P < 0.05$, $r = 0.52$). No significant influence of CHO was found for mean sprint times ($P = 0.35$, $r = 0.27$) or physiological response except at exhaustion, where peak heart rate was significantly greater in the CHO trial ($P < 0.05$, $r = 0.55$).

Study two (n = 7) found a significant influence of [CHO] on intermittent endurance capacity, with a 6% solution increasing intermittent endurance capacity by 34.1% compared with a 10% solution (5.5 ± 0.8 vs. 4.1 ± 1.5 min, $P < 0.05$, $r = 0.76$). No significant difference was observed between the 2% (4.8 ± 1.2 min) and the 6% ($P = 0.10$, $r = 0.63$), or the 2% and the 10% ($P = 0.09$, $r =$

0.63) solution. Distance covered was significantly greater with the 6% solution compared with the 10% solution (931 ± 172 vs. 706 ± 272 m, $P < 0.05$, $r = 0.76$), but was not significantly different compared with the 2% solution (811 ± 230 m, $P = 0.09$, $r = 0.63$) or between the 2% and 10% solutions ($P = 0.11$, $r = 0.61$). Carbohydrate concentration did not significantly influence mean sprint times ($P = 0.38$, $r = 0.42$) or physiological response.

Study three ($n = 11$) reported a significant 21.1% enhancement in intermittent endurance capacity with ingestion of a CHO gel, isoenergetic to the 6% CHO-E solution used in studies 1 and 2, compared with a PLA gel (4.6 ± 2.0 vs. 3.8 ± 2.4 min, $P < 0.05$, $r = 0.67$). Distance covered was also significantly greater in the CHO trial (787 ± 319 vs. 669 ± 424 m, $P < 0.05$, $r = 0.57$). No influence of the CHO gel was observed on mean sprint times ($P = 0.33$, $r = 0.31$) or physiological response.

This thesis reports a significant positive influence of CHO ingestion on the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise. Ingestion of a 6% CHO-E solution was more beneficial than a PLA solution and a 10% CHO-E solution. When compared to a PLA gel, CHO gel ingestion was analogous in efficacy to a 6% CHO-E solution. Carbohydrate ingestion did not significantly influence sprint performance. The influence of CHO on the physiological responses of adolescent team games players to prolonged intermittent, high-intensity exercise was minimal, with the only reported effect being a significantly greater HR at exhaustion in study 1. This thesis has provided evidence to support the use of CHO before and during team games in adolescent team games players, begun to formulate guidelines for CHO ingestion by adolescent team games players, and provided a robust foundation for further study in this field.

Contents

Publications and Presentations

1. Phillips SM, Turner AP, Sanderson MF & Sproule J (In Press) Carbohydrate gel ingestion significantly improves the intermittent endurance capacity, but not sprint performance, of adolescent team games players during a simulated team games protocol. *European Journal of Applied Physiology* DOI: 10.1007/s00421-011-2067-0.

2. Phillips SM, Turner AP, Sanderson MF & Sproule J (In Press) Beverage carbohydrate concentration influences the intermittent endurance capacity of adolescent team games players during intermittent running. *European Journal of Applied Physiology* DOI: 10.1007/s00421-011-2065-2.

3. Phillips SM, Turner AP, Sanderson MF & Sproule J (2011) Beverage carbohydrate concentration influences the intermittent endurance capacity of adolescent team games players during a simulated team games protocol. *Poster presentation at the American College of Sports Medicine Annual Meeting*. Denver, Colorado, 31 May-4 June 2011.

4. Phillips SM, Sproule J & Turner, AP (2011) Carbohydrate ingestion during team games exercise: current knowledge and areas for future investigation. *Poster presentation at the British Association of Sport and Exercise Sciences Annual Student Conference*. University of Chester, Chester, 12-13 April 2011.

5. Phillips SM, Sproule J & Turner AP (2011) Carbohydrate ingestion during team games exercise: current knowledge and areas for future investigation. *Sports Medicine* 41, 7 pp 559-585.

6. Phillips SM, Turner AP, Gray S, Sanderson MF & Sproule J (2010) Ingesting a 6% carbohydrate-electrolyte solution improves endurance

capacity, but not sprint performance, during intermittent, high-intensity shuttle running in adolescent team games players aged 12-14 years. *European Journal of Applied Physiology* 109, 5 pp 811-21.

7. Phillips SM, Turner AP, Gray S, Sanderson MF & Sproule J (2010) Influence of ingesting a 6% carbohydrate-electrolyte solution on sprint performance and endurance capacity during prolonged intermittent, high-intensity exercise in team games players aged 12-14 years. *Oral presentation at the III International Conference of Physical Education and Sport Science: Youth in Physical Education and Sport.* National Institute of Education, Singapore, 25-27 May 2010.

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List of Abbreviations

A	Active
A(G)	Active games players
ANOVA	Analysis of variance
APHV	Age at peak height velocity
ATP	Adenosine triphosphate
[ATP]	Adenosine triphosphate concentration
a-vO_2 diff	Arterio-venous oxygen difference
BLa	Blood lactate
[BLa]	Blood lactate concentration
BM	Body mass
BSA/M	Body surface area to mass ratio
BV	Blood volume
CBF	Cutaneous blood flow
CHO	Carbohydrate
[CHO]	Carbohydrate concentration
CHO-E	Carbohydrate-electrolyte
CHO_{endo}	Endogenous carbohydrate
CHO_{exo}	Exogenous carbohydrate
Cl^-	Chloride
[Cl^-]	Chloride concentration
cm	Centimetres
CNS	Central nervous system
CO_2	Carbon dioxide
CVC	Cutaneous vascular conductance
^{o}	Degrees
^oC	Degrees Centigrade
d.w.	Dry weight
EP	Early-pubertal
ES	Effect size
ET(C)	Endurance trained cyclists

ET(R)	Endurance trained runners
FBF	Forearm blood flow
FFA	Free fatty acid
FFM	Fat-free mass
FVC	Forearm vascular conductance
g	Gram
GD	Gastric discomfort
GE	Gastric emptying
GF	Gut fullness
GI	Gastrointestinal
GLUT4	Glucose transporter type 4
GPA	Greulich-Pyle Atlas
h	Hour
H^+	Hydrogen
$[H^+]$	Hydrogen concentration
HCHO	High carbohydrate
HR	Heart rate
HR_{max}	Maximum heart rate
HT(S)	Highly trained soccer players
K^+	Potassium
$[K^+]$	Potassium concentration
kg	Kilogram
km	Kilometre
$km.h^{-1}$	Kilometres per hour
L^{-1}	Litre
La	Lactate
LCHO	Low carbohydrate
LIST	Loughborough Intermittent Shuttle Test
LP	Late-pubertal
m	Metre
M-LP	Mid- to late-pubertal

MCHO	Moderate carbohydrate
mg	Milligram
min	Minute
ml	Millilitre
MLa	Muscle lactate
[MLa]	Muscle lactate concentration
$m.min^{-1}$	Metres per minute
mmol	millimoles
mOsm	Milliosmoles
MP	Mid-pubertal
MPO	Mean power output
$m.s^{-1}$	Metres per second
Na^{+}	Sodium
$[Na^{+}]$	Sodium concentration
NaCl	Sodium chloride
nl	Nanolitres
O_2	Oxygen
OMNI	Omnibus
PA	Physically active
PCr	Phosphocreatine
[PCr]	Phosphocreatine concentration
PDH	Pyruvate dehydrogenase
PHV	Peak height velocity
P_i	Inorganic phosphate
PLA	Placebo
PO	Power output
PP	Pre-pubertal
PPO	Peak power output
PV	Plasma volume
$\dot{Q}$	Cardiac output
r	Correlation coefficient
r^2	Coefficient of determination

RER	Respiratory exchange ratio
RPE	Ratings of perceived exertion
s	Seconds
SD	Standard deviation
SR	Sweat rate
ST	Sprint trained
SV	Stroke volume
T_{core}	Core temperature
T_{high}	High ambient temperature
T_{rec}	Rectal temperature
T_{sk}	Skin temperature
T(G)	Trained games players
T(R)	Trained runners
T(S)	Trained soccer players
T(SS)	Trained synchronised swimmers
TT	Time-trial
T(V)	Trained in various sports
TW2	Tanner-Whitehouse 2
UT	Untrained
V_{peak}	Peak running velocity
$\dot{V}O_2$	Rate of oxygen consumption
$\dot{V}O_{2max}$	Maximal rate of oxygen consumption
$\dot{V}O_{2peak}$	Peak rate of oxygen consumption
W	Watts

Chapter 1: Introduction

Chapter Aims

This chapter discusses appropriate literature in order to provide a rationale for the aim of the thesis. A brief introduction to carbohydrate ingestion before and during exercise is provided, followed by a more specific summary of current literature into carbohydrate ingestion before and during exercise in children and adolescents. The limitations of this literature, and the associated requirements for further study, are then highlighted. This forms the rationale for the main aim of the thesis, which is stated at the end of the chapter.

1.1 Introduction

The suggestion that carbohydrate (CHO) ingestion during exercise can improve endurance exercise performance (defined as distance covered in a set time or the time to complete a set distance/amount of work; Rollo & Williams, 2009) was first reported in the 1920's (Krogh & Lindhard, 1920; Levine *et al*., 1924). It is now generally accepted that CHO ingestion before and during prolonged (≥ 45 min) moderate- to high-intensity (> 70% maximal oxygen (O_2) uptake ($\dot{V}O_{2max}$)) steady-state exercise can improve exercise performance and endurance capacity (time to exhaustion at a fixed exercise intensity; Tsintzas *et al*., 1996). Furthermore, from the mid 1990's research has consistently reported a significant improvement in intermittent endurance capacity (time to exhaustion at two or more fixed exercise intensities) when CHO is ingested before and during prolonged intermittent, high-intensity exercise that replicates the physiological demand of field-based team games such as soccer (Nicholas *et al*., 1995; Davis *et al*., 1999; Davis *et al*., 2000; Foskett *et al*., 2008). The influence of CHO ingestion on repeated sprint performance during this form of exercise is less consistent (Nicholas *et al*., 1995; Roberts *et al*., 2010; Welsh *et al*., 2002; Winnick *et al*., 2005).

For decades, research investigating CHO ingestion before and during prolonged steady-state, and intermittent, exercise consistently used adult participants.

However, in the last decade work has begun to focus on the influence of CHO ingestion before and during prolonged, steady-state exercise on substrate metabolism and exercise performance in children and adolescents. Using the definitions of Faigenbaum (2000), within this thesis a child is defined as an individual who has not developed secondary sexual characteristics (~ ≤11 years, Tanner stages 1 and 2) and an adolescent is defined as an individual at a maturational stage between childhood and adulthood (~12-18 years, Tanner stages 3 and 4). Throughout the thesis, when children and adolescents are discussed together, the term 'young people' is used.

1.2 Carbohydrate ingestion before and during prolonged, steady-state exercise in young people

1.2.1 Invasive studies in young people

Research involving young people as participants presents a set of unique challenges and requirements from an ethical, legal, and moral perspective (Jago & Bailey, 2001; appendix 1). Within paediatric exercise physiology research, the use of invasive measures such as blood sampling and muscle biopsies to assess variables such as substrate utilisation and the metabolic responses to exercise poses a significant ethical and consensual concern (Armstrong & Van Mechelen, 2008). Regarding the extent of risk allowance associated with paediatric exercise research, it is possible that ethical approval would be granted for obtaining blood samples (Jago & Bailey, 2001). However, this would likely be pursuant to factors such as the frequency of sampling, importance of blood sampling to the research outcomes (Bishop, 2008), the age of the participants, and the view of the individual ethics committee. It should also be considered that even if ethical approval for a particular procedure or test has been obtained, if parental permission and/or child assent is not granted, that procedure cannot be performed. Ethical approval does not preclude parental permission or child assent. Therefore, for reasons of ethics and consent, invasive exercise science studies in young people are often not possible, not appropriate, or both.

1.2.2 Metabolic response of young people to exercise

Young people display the same relative pattern of CHO and fat metabolism with increasing exercise intensity (Brooks and Mercier, 1994) as adults (Aucouturier *et al*., 2008). However, at a given relative exercise intensity, pre-pubertal (PP) children and adolescents exhibit a lower respiratory exchange ratio (RER) than adults (Foricher *et al*., 2003; Riddell *et al*., 2000; Stephens *et al*., 2006; Timmons *et al*., 2003; Timmons *et al*., 2007[a]; Timmons *et al*., 2007[b]). This suggests that young people oxidise greater amounts of fat at a given relative exercise intensity than adults.

Gender differences in substrate utilisation during exercise may be present, with Rowland and Rimany (1995) finding no difference in the RER of 9-13 year old girls compared with young women during cycling. However, Martinez and Haymes (1992) reported that PP girls relied more on fat utilisation and less on CHO metabolism than young women during treadmill running, in line with findings in young males. Conflicting findings in females may be related to the menstrual cycle, as oestrogen and progesterone are known to attenuate total CHO oxidation, potentially due to increased fatty acid availability and oxidation mediated by these same hormones (D'Eon *et al*., 2002). This may also suggest that any potential gender differences in substrate use during exercise may become more prevalent from the onset of sexual maturity in females.

1.2.3 Substrate metabolism and exercise performance of young people with CHO ingestion

The different exercising metabolic profile of young people compared with adults suggests CHO ingestion before and during exercise may not elicit the same metabolic responses, or performance benefits, in young people that have been reported in adults. Therefore, study into CHO ingestion by young people before and during exercise was warranted. Riddell *et al*. (2000) conducted the first study to investigate the influence of CHO ingestion before and during prolonged exercise in

adolescents. Males aged 13-17 years consumed an 8% glucose solution before and during four 30 min bouts of cycling at 60% $\dot{V}O_{2max}$, with a 5 min recovery between each bout. Compared with a water placebo (PLA), glucose ingestion significantly increased total CHO oxidation by 20%, and reduced total fat oxidation and endogenous CHO (CHO_{endo}) use by 45% and 16%, respectively, throughout the protocol. Exogenous CHO (CHO_{exo}) oxidation reached a peak contribution to total exercise energy requirement of 38.4% at 120 min of exercise. This study demonstrated, for the first time, that CHO ingestion can significantly alter the metabolic response of adolescents to exercise, and that young people can oxidise CHO_{exo} in a manner that spares CHO_{endo} stores.

Riddell *et al*. (2001) investigated further by studying the effect of a 6% glucose, and a 6% glucose and fructose solution (3% glucose, 3 % fructose) in 11-14 year old boys during 3 x 30 min cycle bouts at 55% $\dot{V}O_{2max}$, with 5 min recovery between each bout. Ten minutes after the final exercise bout, participants completed a cycle to exhaustion at 90% of peak power output (PPO). Fat oxidation during exercise was significantly lower when CHO was ingested compared with a water PLA. Average rate of total CHO oxidation was significantly higher in the glucose (0.78 $g.min^{-1}$, 56.9% of total energy requirement) and glucose plus fructose (0.74 $g.min^{-1}$, 54.4% of total energy requirement) trials compared with PLA (0.63 $g.min^{-1}$, 47.1% of total energy requirement), with no significant difference between the CHO trials. There was a trend for lower mean CHO_{endo} oxidation rates in the CHO trials compared with PLA, reaching significance at 95 min of exercise. Mean CHO_{exo} oxidation rate was not significantly different between the CHO trials (0.24 and 0.22 $g.min^{-1}$, 16.9 and 15.7% of total energy requirement in the glucose and glucose plus fructose trial, respectively). Mean fat oxidation rate was significantly higher in the PLA trial (0.28 $g.min^{-1}$, 52.9% of total energy requirement) compared with the glucose (0.24 $g.min^{-1}$, 43.1% of total energy requirement) and glucose plus fructose trial (0.25 $g.min^{-1}$, 45.5% of total energy requirement). Time to exhaustion was significantly improved in the glucose plus fructose trial (~202 s) compared with the PLA and glucose trials (~142 and 177 s, respectively). Therefore, this was the first study to demonstrate that

ingestion of CHO during prolonged steady-state exercise can significantly improve the endurance capacity of adolescents.

Timmons *et al*. (2003) conducted the first study to directly compare CHO_{exo} oxidation in children (mean age 9.8 years) and men (mean age 22.1 years). Participants cycled for 60 min at 70% peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$) while ingesting a 6% CHO solution. Mean CHO_{endo} oxidation rate was significantly lower in the boys compared with the men (28.6 and 35.4 $mg.kg^{-1}$ body mass (BM).min^{-1}; 47.7 and 68.8% of total energy requirement, respectively). Total fat oxidation rate was significantly higher in the boys compared with the men (5.0 and 2.8 $mg.kg^{-1}$ BM.min^{-1}; 30.5 and 16.7% of total energy requirement, respectively). In the boys, CHO_{exo} oxidation rate was significantly greater compared with the men (8.8 $mg.kg^{-1}$ BM.min^{-1} and 6.2 $mg.kg^{-1}$ BM.min^{-1}, respectively). Oxidation efficiency of the CHO_{exo} (rate of CHO_{exo} divided by CHO_{exo} ingestion rate and expressed as a percentage) was also significantly greater in the boys compared with the men (36.8 and 26.0%, respectively). Additionally, CHO_{endo} use in the last 30 min of exercise was reduced significantly more in the boys compared with the men (32.5 and 16.5% reduction, respectively). The average percentage contribution of CHO_{exo} to total energy requirement was significantly greater in the boys (21.8%) compared with the men (14.6%). The authors reported that the mean rate of CHO_{exo} oxidation in the boys (~0.26 $g.kg^{-1}$) was significantly greater than the men (~0.19 $g.kg^{-1}$), and was similar to values reported for trained, but higher than values reported for untrained, adults (Burelle *et al*., 1999; Pirnay *et al*., 1995). Therefore, the results of these first three studies suggested that the contribution of CHO_{exo} to total energy requirement during prolonged steady-state exercise may be greater in adolescents than adults during similar exercise protocols (~7-20%, Burelle *et al*., 1999; Massicotte *et al*., 1992; Pirnay *et al*., 1995).

In the only study so far published to investigate the influence of biological maturation on CHO_{exo} utilisation during exercise, Timmons *et al*. (2007[a]) divided twenty boys of the same chronological age (12 years) into PP, early-pubertal (EP), and mid-to late-pubertal (M-LP) groups. Participants cycled for 60 min at 70%

$\dot{V}O_{2max}$ while ingesting a 6% CHO solution. Total fat and CHO oxidation was not significantly different between the three groups. However, CHO_{exo} oxidation contributed significantly more to total energy requirement in the PP and EP group (~30%) compared with the M-LP group (~24%). The authors concluded that the oxidation of CHO_{exo} is inversely related to pubertal status, independent of chronological age.

As mentioned in section 1.2.2, there may be gender differences in the substrate utilisation of young people during exercise. Timmons *et al*. (2007[b]) conducted the only study to so far investigate the influence of CHO ingestion on substrate utilisation during exercise in young females. Two groups of participants (PP and pubertal girls) cycled for 60 min at 70% $\dot{V}O_{2max}$ while ingesting a 6% CHO solution. Carbohydrate ingestion attenuated total fat oxidation by ~50% in the PP girls but not the pubertal girls. Conversely, CHO ingestion decreased CHO_{endo} use by ~15% in the pubertal girls but not the PP girls. Exogenous CHO oxidation rates were not significantly different between groups, averaging ~7.1 and 6.8 $mg.kg^{-1}$ $BM.min^{-1}$ in the PP and pubertal groups, respectively, and contributing ~19% to the total exercise energy requirement. This appears to contrast with prior findings in boys. However, the gap in pubertal status between the two groups was small, which may, at least in part, explain the lack of between-groups difference in CHO_{exo} utilisation (Timmons *et al*., 2007[b]).

1.3 Further Research Requirements

The literature summarised in section 1.2.3 represents the first investigations of CHO ingestion before and during prolonged exercise in young people. A limitation of this work is that all of the protocols employed steady-state exercise. This represents a gap in the research literature. A large population of young people are actively involved in prolonged intermittent, high-intensity exercise via participation in field-based team games such as soccer, rugby and field-hockey (Malina, 2005; Sport England, 2003; SportScotland, 2008). However, research investigating the physiological and metabolic responses, or methods of performance enhancement, of

young people during this form of exercise is not currently available. Metabolic responses and fuel use during prolonged intermittent exercise are known to be different to those of steady-state exercise. Christmass *et al*. (1999) demonstrated a 1.2 times higher ($P < 0.05$) rate of CHO_{endo} oxidation during 90 min of sustained intermittent compared with continuous running at the same overall $\dot{V}O_2$. This indicates that CHO ingestion requirements during prolonged intermittent exercise may be different to those during prolonged steady-state exercise. Therefore, findings from research investigating CHO supplementation before and during prolonged steady-state exercise cannot be confidently applied to prolonged intermittent exercise. Instead, the study of CHO ingestion before and during prolonged intermittent exercise should be investigated separately in the literature. Furthermore, young people display a different metabolic response to exercise compared with adults (section 1.2.2). This, coupled with the potential ability of young people to oxidise CHO_{exo} at similar, or greater, rates than adults (section 1.2.3), indicates that the CHO requirements of young people during exercise may be different to those of adults (Montfort-Steiger & Williams, 2007). Therefore, data derived from adult studies should not be applied to young people. Specific research in areas such as CHO ingestion during prolonged intermittent, high-intensity exercise, using young people as research participants, is required (Montfort-Steiger & Williams, 2007).

1.4 Thesis aim

The aim of this thesis is to investigate the influence of CHO ingestion immediately before, and during, prolonged intermittent, high-intensity exercise on the endurance capacity, sprint performance, and physiological responses of adolescent team games players.

Chapter 2: Literature Review

Chapter Aims

This chapter provides a critical discussion of research investigating key aspects of developmental exercise physiology, the activity profile and physiological demand of youth team games, and carbohydrate ingestion before and during prolonged intermittent exercise, field-based team games, and prolonged intermittent, high-intensity exercise. This discussion will provide a rationale for the thesis research questions, which are stated at the end of the chapter.

2.1 Developmental exercise physiology

2.1.1 Introduction

Young people grow and mature at individual rates, with metabolic and hormonal responses to exercise fluctuating as they progress through childhood and adolescence (Boisseau & Delamarche, 2000). Determination of the biological maturation status of young research participants is important, in order to quantify the influence of biological maturation state on measured variables. This is particularly important in cross-sectional and longitudinal research, which often has the goal of determining the influence of biological maturation on specific outcome measures. The method of maturation assessment employed will depend on factors such as ethical approval and restrictions, parental permission and child assent, equipment availability, and the experience of the researcher in using the specific method(s). A summary of the most common methods of biological maturation assessment is contained in appendix 2.

Knowledge of the physiological responses of adolescents to exercise, particularly prolonged intermittent, high-intensity exercise, is sparse, due in part to ethical and consensual concerns that restrict the use of invasive measurements. However, it is important to address concepts of developmental physiology that are of direct relevance to the research undertaken in this thesis, to facilitate understanding of the data presented in subsequent chapters.

2.1.2 Heart rate response to exercise

The literature discussed in this section is summarised in table 2.1. At absolute submaximal intensities, adolescents have a higher heart rate (HR) than adults (Cheatham *et al*., 2000; Rowland *et al*., 1997; Turley, 1997). The relative O_2 cost of a given workload is constant regardless of age, and a critical cardiac output ($\dot{Q}$) is required. The lower absolute stroke volume (SV) of adolescents compared with adults therefore necessitates a higher HR to generate the required $\dot{Q}$ (Turley, 1997; Turley & Wilmore, 1997). The lesser SV of adolescents is only partially compensated for by this greater HR (Rowland *et al*., 1997; Turley & Wilmore, 1997), with a possible additional compensation in the form of a proportionally higher arterio-venous O_2 difference (a-vO_2 diff; Fawkner & Armstrong, 2003; Turley & Wilmore, 1997). However, a-vO_2 diff has also been reported as significantly lower in young people compared with adults during submaximal and maximal exercise (Cheatham *et al*., 2000; Nottin *et al*., 2002; Rowland *et al*., 1997). While more research is required, the inconclusive findings may be due to age-related changes in haemoglobin concentration and blood volume (BV) redistribution (Nottin *et al*., 2002; Rowland *et al*., 1997). Young females display a higher exercising HR at a given exercise intensity than young males, due in large part to a smaller exercising SV (Turley, 1997).

The time-constant of HR recovery following an exercise bout is significantly faster in young people than adults, perhaps due to greater central parasympathetic efferent nervous activity to the heart in young people (Ohuchi *et al*., 2000) and, possibly, smaller exercise-induced increases in catecholamine activity (Baraldi *et al*., 1991), although this requires confirmation (Ratel *et al*., 2006[a]).

Table 2.1 Summary of observational research investigating heart rate responses of young people during exercise (review articles are not summarised in this table).

Study	Participants	Protocol	Key Findings	Limitations
Cheatham *et al*. (2000)	8 PA boys, 10-13 years 10 PA males, 18-25 years	40 min cycle at ventilatory threshold	Significantly higher HR and lower SV, $\dot{Q}$ and a-vO_2 diff in boys	Expression of cardiovascular variables relative to body size would have enabled a relative comparison between boys and men at ventilatory threshold
Nottin *et al*. (2002)	17 PA boys, 11.7 years 23 PA men, 21.2 years	Incremental cycle test to exhaustion	No significant difference in cardiovascular variables between boys and men when scaled for body size a-vO_2 diff significantly greater in men	No notable limitations
Rowland *et al*. (1997)	15 PA boys, 10.9 years 16 PA men, 30.7 years	Incremental cycle test to exhaustion	No significant differences in body-size relative cardiovascular variables between boys and men at rest, submaximal, or maximal exercise	No notable limitations
Turley & Wilmore (1997)	12 PA boys, 9.1 years 12 PA girls, 8.8 years 12 PA males, 22.8 years 12 PA females, 23.6 years	Incremental cycle and treadmill test to exhaustion 3 x 14-18 min steady-state treadmill and cycle exercise, 3-5 min recovery	Absolute $\dot{Q}$ and SV significantly lower at a given O_2 consumption in children compared to adults HR and a-vO_2 diff significantly higher in children	Further expression of cardiovascular variables relative to body size would have enabled a relative comparison between children and adults
Vinet *et al*. (2002)	7 PA boys and girls, 10.8 years 8 PA men and women, 22.4 years	Incremental cycle test to exhaustion	Similar body-size relative cardiovascular function	Gender comparison could have been carried out

PA = physically active

2.1.3 Thermoregulation

Young people display a different thermoregulatory strategy during exercise compared with adults, due to differences in sweat rate (SR), body surface area-to-mass ratio (BSA/M), metabolic demand during weight-bearing exercise, and acclimatisation to heat (Rowland, 2008). Acclimatisation to heat will not be discussed, as different ambient temperatures were not employed in this thesis. For more information on acclimatisation of young people, the reader is referred to Rowland (2008).

2.1.3.1 Sweat rate

The articles discussed in section 2.1.3 are summarised in table 2.2. Pre-pubertal children have a lower absolute SR than adults (Inbar *et al*., 2004; Inoue *et al*., 2004; Meyer *et al*., 1992; Shibasaki *et al*., 1997). This has been attributed to a lower SR per gland due to smaller gland size and decreased gland sensitivity to changes in ambient temperature (Falk, 1998; Rowland, 2008), attenuated hormonal effects (Falk, 1998; Inoue *et al*., 2004), and a lower sweat gland metabolic capacity (Falk, 1998). Delayed onset of sweating and lower SR has been suggested to increase children's risk of heat stress during exercise (Bytomski & Squire, 2003). However, this is not supported in the literature (Falk & Dotan, 2008; Rowland, 2008). Furthermore, while mean absolute SR is lower in children, evaporative heat loss and sweating efficiency (evaporative heat loss relative to total body sweat) is significantly higher in PP children compared to young adults (Inbar *et al*., 2004). This suggests that lower SR in children does not mean lower evaporative heat loss during exercise (Falk *et al*., 1992[a]; Inbar *et al*., 2004; Rowland, 2008). Greater sweating efficiency in PP children may be explained by smaller, more diffusely spaced sweat drops that evaporate more readily (Inbar *et al*., 2004).

Children also appear more efficient at convective heat loss. Significant negative correlations between age and exercising forearm blood flow (FBF), forearm vascular conductance (FVC), cutaneous blood flow (CBF) and cutaneous vascular

conductance (CVC) have been reported from ~5-85 years in males and females (Falk *et al*., 1992[b]; Hodges *et al*., 2010; Martin *et al*., 1995; Shibasaki *et al*., 1997). These relationships appear stronger in males (Hodges *et al*., 2010). Evidence suggests that these already enhanced convective mechanisms are further improved in highly trained adolescents compared with untrained age- and maturation-matched controls (Roche *et al*., 2010).

Absolute SR, SR per unit body surface area (figure 2.1A) and per sweat gland (figure 2.1B), and rate of heat storage increases, and population density of heat activated sweat glands decreases, as children advance through puberty (Falk *et al*., 1992[a]; Falk *et al*., 1992[b]). Sweat rate per gland is negatively associated with population density, helping to explain the greater absolute SR response with increasing age (Falk *et al*., 1992[a]). Transition to an adult-like thermoregulatory process, at least in high ambient temperature (T_{high}), occurs at some stage after puberty (Falk *et al*., 1992[b]).

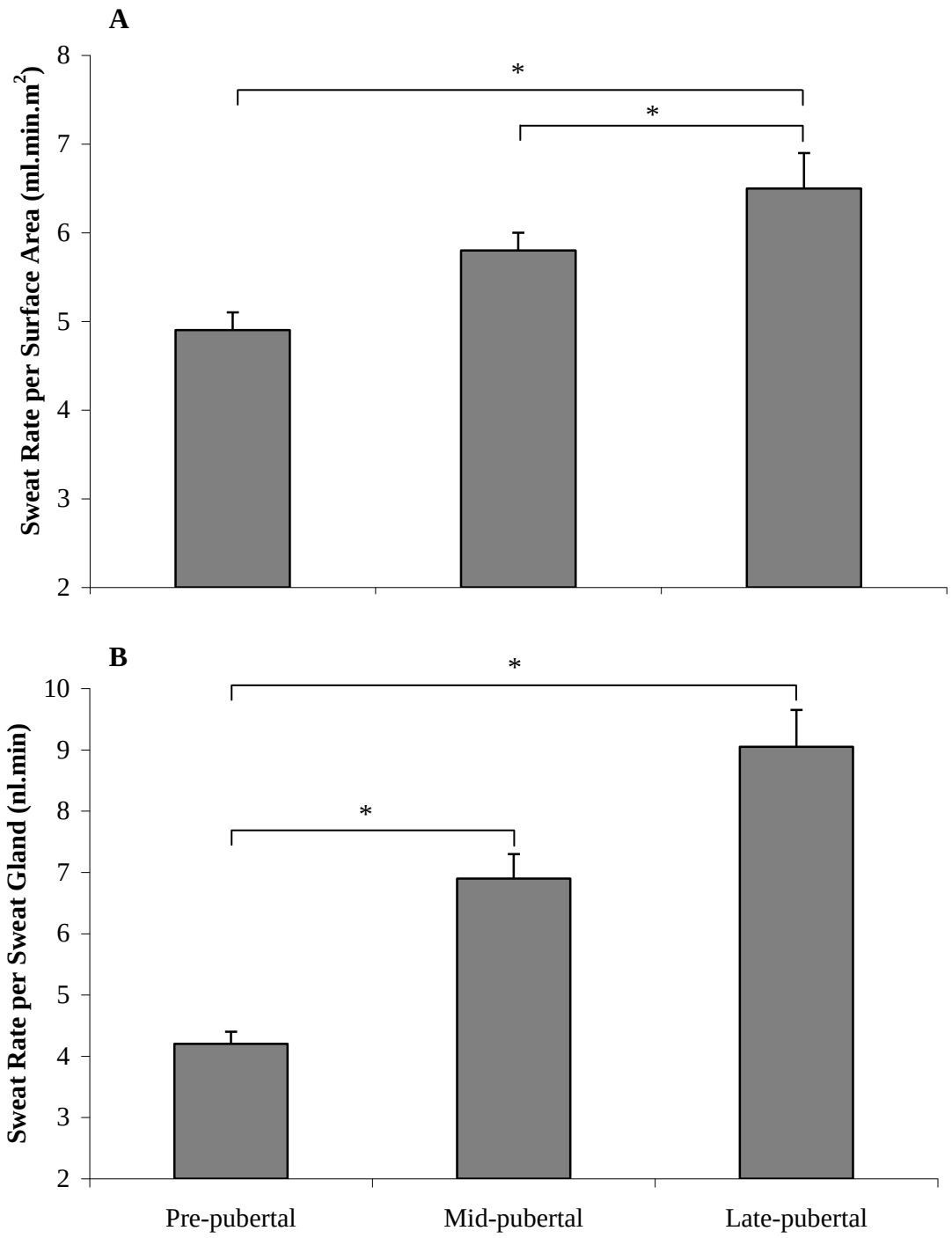

Figure 2.1 Sweat rate per unit of skin surface area (ml.min.m^2, A) and per sweat gland (nl.min, B) in pre-, mid-, and late-pubertal boys during cycle ergometer exercise at 50% peak oxygen consumption in 42^{o}C heat and 20% relative humidity. Sweat rate per unit surface area and per sweat gland increased significantly with increased maturation. * $P < 0.01$. Data from: Falk *et al*. (1992[a]; 1992[b]).

2.1.3.2 Sweat composition

Sodium (Na^+) is the most abundant electrolyte in adolescent sweat. However, Meyer *et al*. (1992) found that young adult males (mean age 22.4 years) had significantly greater absolute and BM-relative sweat Na^+ concentration ($[Na^+]$) than PP boys (mean age 9.1 years), and significantly greater sweat chloride (Cl^-) concentration ($[Cl^-]$) than PP and pubertal boys (mean age 11.4 years). These differences are only partially explained by the lower SR of young people (Falk, 1998), with age-related differences in the electrolyte transport mechanism of sweat glands also involved (Meyer *et al*., 1992). In contrast to $[Na^+]$ and $[Cl^-]$, young people appear to have non-significantly greater sweat potassium (K^+) concentration ($[K^+]$) than adults, with no significant maturational influence (Meyer *et al*., 1992).

The lower sweat $[Na^+]$ and $[Cl^-]$ of young people questions whether they need to replace electrolytes during exercise (Falk, 1998). Ingesting different amounts of Na^+ during intermittent cycling for 2 h in 35^{o}C ambient temperature elicited no effects on plasma $[Na^+]$, exercise performance or thermoregulation in 9-12 year old children (Meyer *et al*., 1993). Inclusion of Na^+ in drinks consumed by young people may be beneficial for enhancing fluid absorption from the intestine (Lambert *et al*., 1997), although this is not always demonstrated (Gisolfi *et al*., 2001), and maintaining plasma osmolality and, therefore, the thirst drive (Stachenfeld, 2008). However, the thirst drive appears to be better developed in children than adults (Meyer *et al*., 1993), although more recent work suggests the degree of fluid intake by young people may depend to some extent on drink palatability and previous behavioural reinforcement (Bergeron *et al*., 2006; section 2.1.4).

2.1.3.3 Body surface area to mass ratio and body heat storage

Individuals with a greater BSA/M should be able to expedite heat dissipation via dry heat loss mechanisms, reduce heat storage, and facilitate thermoregulation during exercise in thermoneutral conditions (Rowland, 2008). The BSA/M of young people is significantly greater than that of adults until ~13 years of age, after which values

begin to stabilise and do not differ significantly from adults (Rowland, 2008, figure 2.2).

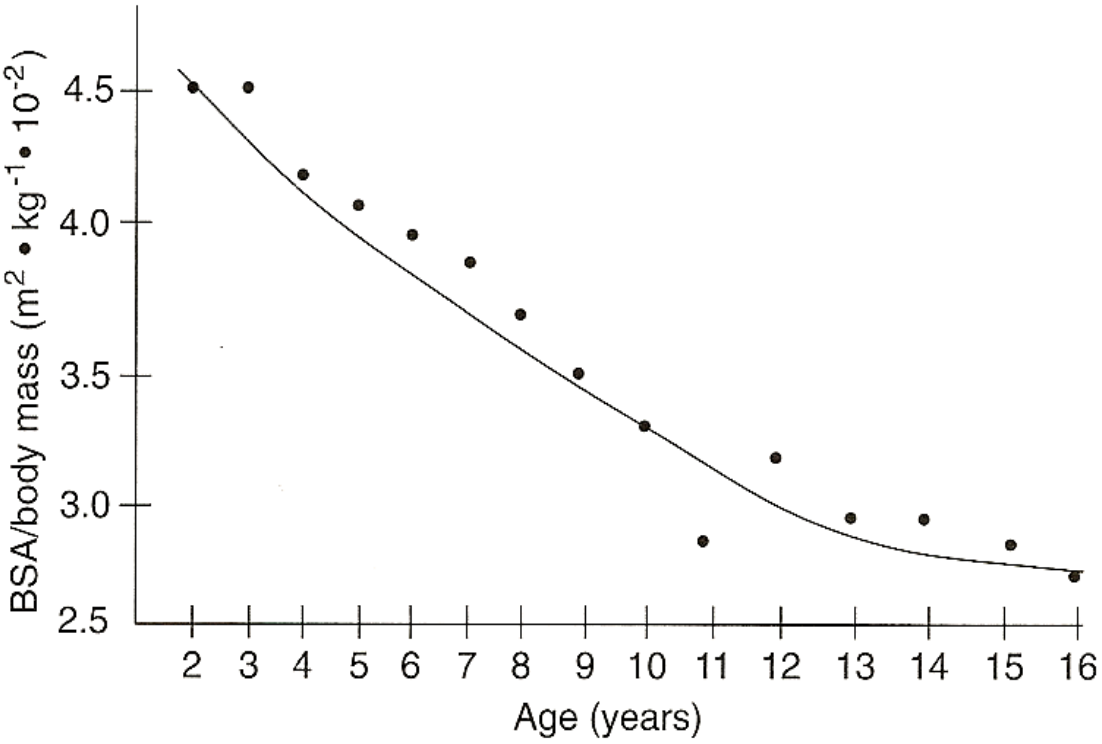

Figure 2.2 The relationship between body surface area to mass ratio and age, demonstrating an almost linear decline with age until ~13 years, where values begin to plateau. It is from ~13 years where values between young people and adults no longer differ significantly. Adapted from: Rowland (2005).

Adult studies show negative correlations between BSA/M and heat storage while running in the heat (Marino *et al*., 2000), supporting the suggestion that young people should be able to lose heat via dry, non-evaporative processes and maintain a stable core temperature (T_{core}) at least as effectively as adults. Conversely, when ambient temperature exceeds skin temperature (T_{sk}) a high BSA/M may facilitate convective heat absorption from the environment, placing young people at a disadvantage (Bar-Or *et al*., 1980). However, research investigating thermoregulatory responses during exercise in the heat has shown no significant difference in rectal temperature (T_{rec}) or T_{sk} increases between PP, MP, and LP children, or children and adults (Falk *et al*., 1992[b]; Inbar *et al*., 2004; figure 2.3). In

fact, the rate of heat storage calculated by Inbar *et al*. (2004) was lowest in PP participants, when the difference in BSA/M ratio compared to adults is at its greatest (figure 2.2). This study was conducted in 41^{o}C ambient temperature, and supports the notion that, with the exception of extreme environmental conditions, young people are as capable as adults at thermoregulation during exercise (Falk & Dotan, 2011). This may be, at least partly, due to the seemingly more efficient convective heat loss mechanisms of children (section 2.1.3.1). It should be noted, however, that factors including fitness, gender, type and duration of exercise, body composition, particularly the percentage of fat mass, and the degree of heat acclimatisation can influence the effect of BSA/M on heat storage and loss (Havenith, 2001).

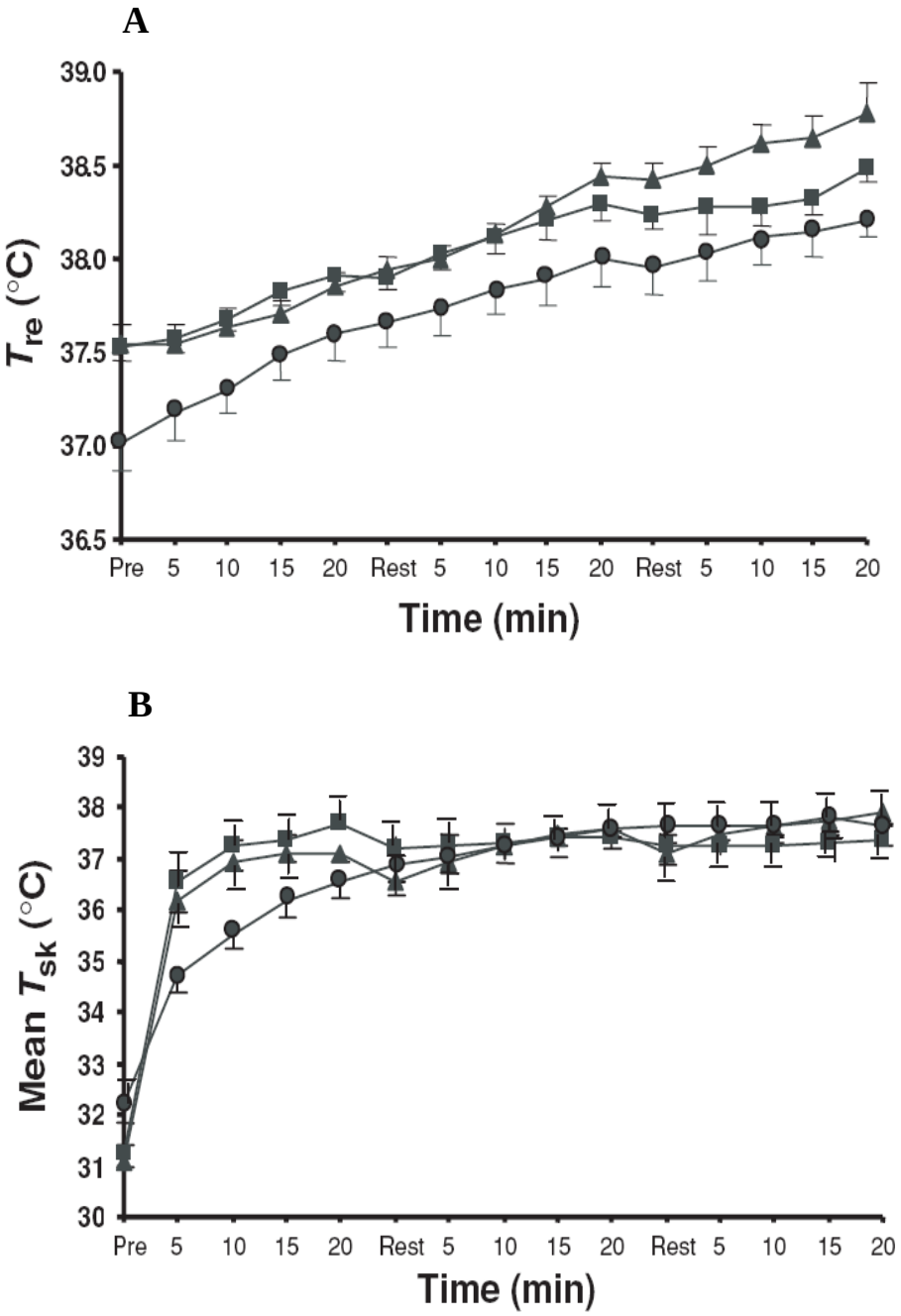

Figure 2.3 Mean rectal (°C, A) and skin (°C, B) temperatures during 3 x 20 min bouts of cycling at 50 ± 1% maximal oxygen consumption separated by 7 min recovery in 41°C heat and 21% relative humidity. ■ = pre-pubertal boys (9.4 ± 0.6 years); ▲ = young men (22.7 ± 0.8 years); ● = elderly men (71.0 ± 1.0 years). For both measurements, no significant age-dependent difference was found at any time point. Data is mean ± SEM. Adapted from: Inbar *et al*. (2004).

2.1.3.4 Metabolic heat production during weight-bearing exercise

During weight-bearing exercise at the same absolute workload, young people demonstrate a higher $\dot{V}O_2$ and, therefore, a higher metabolic cost, than adults (McCann & Adams, 2003). The most likely reason for this is that, when exercising at the same absolute workload, young people will be exercising at a greater relative intensity than adults (Rowland, 2008). Further supporting this, it has been demonstrated that when the metabolic cost of exercise at a given intensity is expressed relative to stride length (a variable influenced by body size), the difference in metabolic cost between young people and adults is negated (Unnithan & Eston, 1990).

The importance of relative muscular work is crucial. Age-dependent differences in metabolic heat production during weight-bearing exercise should be considered in terms of relative exercise intensity, as thermoregulatory mechanisms respond to heat production in respect to relative, as opposed to absolute, exercise intensity (Gant *et al*., 2004; Rowland, 2008). Furthermore, during real-world sporting activity, young people exercise at a lower absolute intensity than adults (Rowland, 2008). With these considerations in mind, it is expected that during exercise at the same appropriately scaled relative workload, metabolic heat production per unit BM would be similar between young people and adults. Consequently, metabolic heat production should not challenge the thermoregulation of young people to a greater extent than it would in adults.

Table 2.2 Summary of research investigating thermoregulation during exercise in young people (review articles are not summarised in this table).

Study	Participants	Protocol	Key Findings	Limitations
Bar-Or (1980)	11 boys, 10-12 years	Repeated 20 min cycle with 25 min recovery at 45% VO_{2max} in 39°C heat	When ambient temperature exceeds T_{sk}, a higher BSA/M ratio may absorb heat from the environment	Adult participants were not used for comparison
		Participants consumed fluid *ad libitum* or in sufficient amounts to replace fluid losses, in a randomised fashion	Exercising children progressively dehydrate when not forced to drink	
			At equal levels of % weight loss children have a greater rise in T_{rec} than adults	
Falk *et al*. (1992[a])	16 PA PP males, 10.8 years 15 PA MP males, 13.6 years 5 PA LP males, 16.2 years	2 x 20 min cycle at 50% $\dot{V}O_{2max}$, 10 min rest (trial conducted in 42°C heat)	Rise in HR, T_{rec} and T_{sk} did not differ between groups	No notable limitations
			Whole body SR was significantly greater in the LP group compared with the PP group	
			Population density of heat activated sweat glands was significantly greater in the PP group	
			Mean area of sweat drops was significantly greater in the LP group	
			Sweat rate per gland was inversely related to population density and positively related to mean area of sweat drops	
			Maturation appears to be accompanied by a decreased density of heat-activated sweat glands but increased sweat drop area, reflected by an increased SR per gland	

Falk *et al*. (1992[b])	10 PA PP males, 12.2 years 13 PA MP males, 13.6 years 8 PA LP boys, 16.7 years	2 x 20 min cycle at 50% $\dot{V}O_{2max}$, 10 min rest (trial conducted in 42°C heat)	Rise in HR, T_{re} and T_{sk} did not differ between groups Forearm blood flow was significantly higher in the PP group compared with the LP group Rate of heat storage was significantly greater in the LP group despite a significantly higher SR in this group compared with the PP group Body mass-relative SR not different between groups Transition to an adult-like thermoregulatory response may occur at a later stage, but not during puberty	No notable limitations
Havenith (2001)	Trial 1: 14 males and 16 females, 23.1 years Trial 2: 18 males and 7 females, 25.6 years	30 min heat acclimation period, then 60 min cycle at 60 W Participants exercised in 45°C (20% relative humidity) heat, or 35°C (80% relative humidity) heat, in a randomised fashion	Negative correlations between BSA/M & T_{rec}, giving bigger participants an advantage	No notable limitations
Hodges *et al*. (2010)	129 males and 93 females, 16-76 years	5 min forearm vascular occlusion, local skin heating at 42°C, incremental treadmill run to exhaustion	Significant negative correlations between age and resting FBF and peak FBF, CBF Correlations were stronger in males than females	Cross-sectional study design potentially problematic concerning rate of decline in $\dot{V}O_{2max}$ with age Some criteria for determining a maximal test may not have been appropriate for young participants
Inbar *et al*. (2004)	24 PA males, 9.4-71.0 years	3 x 20 min cycle at 50% $\dot{V}O_{2max,}$ 7 min rest (trial conducted in 41°C heat)	Whole body and BSA-relative SR was significantly lower in the children Rise in T_{rec} and T_{sk} was not different between	No information regarding maturation assessment procedures for PP participants

			groups Increases in absolute and BM-relative heat storage were significantly greater in the young and old adults BM-relative evaporative cooling and sweating efficiency were greatest in the children Children required significantly more heat energy to raise T_{core} compared with the young and old adults Data suggested that children are the most efficient thermoregulators	Some criteria for determining a maximal test may not have been appropriate for young participants
Martin *et al*. (1995)	43 males and 31 females, 5-85 years	Assessment of FBF at thermoneutral (32-34^{o}C) & 42^{o}C T_{sk}	Maximal heat-induced forearm vasodilation decreases linearly from young adulthood through to old age Maximal FVC is greater in children and a steep rate of decline occurs from 5 years through to adulthood Maximal FVC not significantly related to gender, adiposity, resting blood pressure, or regular physical activity level	No notable limitations
McCann & Adams (2003)	36 PA children, 10.3 years 23 PA adolescents, 15.7 years 24 PA adults, 35.4 years	6 min running bouts at 1.6 – 3.1 m.sec^{-1}	Body mass-specific $\dot{V}O_2$ was greater in children than adolescents, and in adolescents than adults Size-independent metabolic energy cost was not different between children and adults, but was lower in adolescents, indicating greater running economy in this group	Method of calculating size-independent metabolic energy cost cannot identify and quantify specific qualitative differences affecting economy

Meyer *et al*. (1992)	8 PP males, 9.1 years 9 pubertal males, 11.7 years 8 males, 21.4 years 10 PP females, 9.1 years 8 pubertal females, 11.0 years 8 females, 23.4 years	2 x 20 min cycle at 50% $VO_{2max,}$ 10 min rest (42^oC)	Children had a lower absolute and BSA-relative SR than young adults Sweat $[Na^+]$ & $[Cl^-]$ increased significantly with maturation Sweat $[K^+]$ was significantly lower in young adults than children Sweat $[Na^+]$ & $[Cl^-]$ relative to BM was higher in young adults compared with PP and pubertal participants, with no maturational differences for $[K^+]$ No gender differences within the same maturational group	Some criteria for determining a maximal test may not have been appropriate for young participants
Meyer *et al*. (1993)	5 boys and 4 girls, 9-12 years	1 x 20 min & 2 x 15 min cycle at 50% VO_{2peak}, 10 min rest Participants consumed three solutions (0; 8.8; 18.5 $mEq.L^{-1}$ Na^+) in a randomised fashion.	Sweat $[Na^+]$ was not significantly different between the three trials	No notable limitations
Roche *et al*. (2010)	17 HT(S) boys, 14.6 years 9 UT boys, 15.6 years Participants matched for age and maturation	Incremental cycle test to exhaustion	Resting and peak FBF significantly higher in trained participants Forearm vascular conductance significantly greater in trained participants Chronic training can enhance microvascular endothelial vasodilation in adolescents	Potential inaccuracy associated with self-assessment of maturity status Criteria for attainment of $\dot{V}O_{2peak}$ of HR >180 beats per min appears somewhat low Difference in FBF and FVC may have been due to increased fat mass in UT participants rather than training status
Shibasaki *et al*. (1997)	7 boys, 10-11 years 11 men, 21-25 years	45 min cycle at 40% VO_{2max} (30^oC)	Rise in T_{rec} & HR was not different between groups	Vague information regarding maturation assessment procedures

			Total body SR & local SR was significantly lower in children compared with adults Lower SR in children was attributed to a lower output per heat activated sweat gland Cutaneous blood flow was significantly greater in the chest & back compared with the men Children displayed lower mean T_{sk} after starting to sweat, whereas adults remained unchanged Children can thermoregulate as efficiently as young men due to greater vasodilation of the trunk	
Unnithan & Eston (1990)	10 PA PP boys, 9-10 years 10 PA men, 18-25 years	Submaximal treadmill running at various speeds	At all running speeds, $\dot{V}O_2$ was greater in the boys than the men Boys compensated for a shorter stride length by demonstrating a higher stride frequency than men at all running speeds When $\dot{V}O_2$ was compared relative to each stride, no differences were observed between boys and men at any running speed	No notable limitations

PA = physically active; **PP =** pre-pubertal; **MP =** mid-pubertal; **LP =** late-pubertal; **HT(S) =** highly trained soccer players; **UT** = untrained

2.1.4 Voluntary fluid intake during exercise

Research discussed in this section is summarised in table 2.3. Young people display inconsistent drinking practices during exercise, perhaps due to poor understanding and/or education of the need to maintain adequate hydration (Molloy *et al*., 2008; Naughton & Carlson, 2008). Bar-Or *et al*. (1980) reported *ad libitum* plain water consumption equalling 66% of fluid losses during 80-100 min cycling in 39^{o}C ambient temperature in partially heat-acclimatised 10-12 year old boys, equating to a mean BM loss of 1-2%. Other studies report BM losses ranging from 0.65-0.94% (Rivera-Brown *et al*., 1999; Wilk & Bar-Or, 1996) during prolonged, moderate-intensity exercise in T_{high} with heat-acclimatised or non-acclimatised participants. It therefore appears that young people do not prevent mild dehydration when voluntarily ingesting plain water during exercise in 30-39^{o}C ambient temperature, regardless of the degree of acclimatisation. Rowland *et al*. (2008) found no significant dehydration when PP children cycled to exhaustion in 19^{o}C and 30^{o}C ambient temperatures while consuming plain water *ad libitum*. However, the total duration of the trial (~30-40 min) was notably shorter than the ~3 h sessions conducted in other work (Bar-Or *et al*., 1980; Wilk & Bar-Or, 1996).

Fluid composition has a significant impact on voluntary ingestion by young people during exercise. When exercising for 90-180 min at 45-50% $\dot{V}O_{2max}$ in 35^{o}C ambient temperature, children drank 44.5% more grape-flavoured fluid compared with unflavoured water (Bar-Or & Wilk, 1996). Furthermore, when CHO (6% concentration) and Na^{+} Cl^{-} (NaCl) was added to a flavoured drink, voluntary dehydration during prolonged intermittent exercise in the heat in 9-13 year old boys was prevented (Rivera-Brown *et al*., 1999; Wilk & Bar-Or, 1996). Wilk *et al*. (2010) demonstrated that heat-acclimatised adolescent runners can appropriately gauge fluid intake and maintain euhydration during prolonged intermittent treadmill running in 30^{o}C ambient temperature and 60-65% relative humidity when consuming water, flavoured water, or flavoured water with CHO and NaCl *ad libitum*. The fact that participants were trained runners undertaking a running protocol may be indicative of an enhanced ability to judge comparative fluid losses and requirements during

exercise, as well as a possible experience-related increase in knowledge and awareness of the importance of adequate fluid ingestion.

Rowland (2011) acknowledged that it is difficult to formulate broad, effective guidelines for fluid intake in young people given the numerous influencing factors governing fluid requirements. These authors suggested that *ad libitum* fluid ingestion is sufficient to avoid performance-attenuating fluid losses, but also stated that young athletes may not respond adequately to the thirst drive due to distractions during exercise. If this is the case, young team games players may be particularly susceptible due to the abundance of potential distractions during games. Therefore, relying simply on *ad libitum* fluid intake during team games may not be sufficient for young players. This is supported by the observation of young soccer players arriving to training sessions in a hypohydrated state, and failing to consume voluntarily sufficient fluid during training to offset losses (Silva *et al*., 2011). However, performance was not assessed in this study. Furthermore, the efficacy of relying on *ad libitum* fluid intake during team games should be questioned, given the limited opportunities to consume fluid during this form of exercise (Clarke *et al*., 2008). More work should investigate fluid ingestion practices by young people during team games across a range of ambient temperatures.

Table 2.3 Summary of research investigating voluntary fluid intake during exercise in young people (review articles are not summarised in this table).

Study	Participants	Protocol	Key Findings	Limitations
Bar-Or *et al*. (1980)	11 partially heat-acclimatised boys, 10-12 years	Repeated 20 min cycle with 25 min recovery at 45% VO_{2max} in 39^{o}C heat Participants consumed fluid *ad libitum*, or in sufficient amounts to replenish fluid losses, in a randomised fashion	Voluntary fluid intake induced a progressive increase in fluid loss and a lower urine output during exercise Sweat rate, T_{rec}, T_{sk}, HR, & RPE did not differ between trials, but the rate of rise in T_{rec} was positively correlated with hypohydration level Exercising children progressively dehydrate when not forced to drink	Unclear as to the justification for only partially acclimatising participants
Molloy *et al*. (2008)	12 teachers from primary schools in Midlands of Ireland	In-depth interviews	Respondents had a poor knowledge of hydration requirements and health benefits Low water intake amongst teachers and pupils associated with barriers such as class disruption and need to urinate	Study did not specifically involve children
Rivera-Brown *et al*. (1999)	12 T(V) heat-acclimatised boys, 13.4 years	4 x 20 min cycle at 60% maximal aerobic power, 25 min rest in 30.4^{o}C heat Participants consumed plain water or a 6% CHO solution with 18 mmol.L^{-1} Na^{+} *ad libitum*, in a randomised fashion	Total fluid intake was significantly greater in the CHO trial Euhydration was maintained in the CHO trial, with a dehydration in the water trial Increase in T_{rec}, HR, and all perceptual variables did not differ between trials A flavoured CHO drink prevented voluntary dehydration	Some criteria for determining a maximal test may not have been appropriate for young participants

Rowland *et al.* (2008)	8 PP non-acclimatised boys, 11.7 years 8 non-acclimatised men, 31.8 years	Cycle at 65% VO_{2peak} to exhaustion Participants completed the protocol in 19°C and 31°C heat, in a randomised fashion	Voluntary fluid intake was similar during exercise in the heat between children and adults No significant dehydration encountered in children in either trial	Short exercise protocol with no set end-point may have confounded the results
Silva *et al.* (2011)	20 T(S) boys, 17.2 years	Three 2.5 h soccer training sessions on consecutive days Measures of hydration status recorded before and after each training session	Players began each training session mildly hypohydrated Fluid intake during training did not match fluid losses	Performance measures were not taken to correlate with hydration status
Wilk & Bar-Or (1996)	12 PA boys, 10.4 years	4 x 20 min cycle at 50% VO_{2max}, 25 min rest in 35°C heat Participants consumed plain water, grape flavoured water, or grape flavoured water with 6% CHO solution & 18 $mmol.L^{-1}$ Na^+ *ad libitum*, in a randomised fashion	Total fluid intake was significantly greater in the flavoured water & flavoured water & CHO trials Hypohydration occurred in the water & flavoured water trials, with slight hyperhydration in the flavoured water & CHO trial Other physiological and perceptual responses did not differ significantly between trials Flavouring of water reduces children's voluntary dehydration, but further addition of CHO & Na^+ prevents it altogether	No objective criteria for establishing a maximal effort during $\dot{V}O_{2max}$ test
Wilk *et al.* (2010)	8 heat-acclimatised T(R) boys, 13.7 years	5 x 15 min treadmill runs at 65% $\dot{V}O_{2peak}$, 5 min rest intervals, followed by run to exhaustion at 90% $\dot{V}O_{2peak}$. Conducted in 30°C heat, 60-65% relative humidity Participants consumed plain	Voluntary fluid intake similar to fluid losses in all trials No significant dehydration encountered in any trial Time to exhaustion did not differ between trials	No notable limitations

		water, grape flavoured water, or grape flavoured water with 6% CHO solution & 18 mmol.L^{-1} Na^{+} *ad libitum*, in a randomised fashion	

T(V) = trained in various sports**;** **PP =** pre-pubertal **;** **T(S)** = trained soccer players; **PA** = physically active; **T(R) =** trained runners

2.1.5 Substrate utilisation during exercise

Knowledge of the metabolic responses of young people to exercise is limited, and there is currently no specific data on the metabolic responses or substrate use of this population to prolonged intermittent, high-intensity exercise. Clearly, ethical restrictions regarding the use of invasive measurements contributes to this (Boisseau & Delamarche, 2000). The following sections discuss what is currently known regarding substrate use in young people during exercise. Articles discussed in this section are summarised in table 2.4.

2.1.5.1 Phosphocreatine

Data regarding the contribution of phosphocreatine (PCr) to energy requirement during exercise in young people is conflicting, with some work reporting significant reductions in PCr contribution (Tonson *et al*., 2010), and others no significant difference in contribution (Barker *et al*., 2008; Taylor *et al*., 1997) compared with adults. There is similar confusion regarding end-exercise PCr kinetics in young people, with some authors reporting significantly faster PCr recovery in young people compared to adults (Fleischman *et al*., 2010; Kuno *et al*., 1995; Tonson *et al*., 2010), and others no difference (Barker *et al*., 2008; Barker *et al*., 2010; Willcocks *et al*., 2010). Numerous confounding factors can make reaching a consensus in this area difficult. These include:

- Inter-study differences in the exercise protocol and maturation status of participants used.
- Differences in end-exercise metabolic conditions between young people and adults (Kuno *et al*., 1995).
- Sampling different proportions of a muscle, and therefore different muscle fibre types, due to differences in muscle size between young people and adults (Barker *et al*., 2008).
- Differing physical fitness between participants.

- Failure to report error associated with PCr kinetics parameters (Barker *et al*., 2008).

As a result, a consensus on the PCr response of young people to exercise is not available.

2.1.5.2 Carbohydrate and fat

Mainly for ethical reasons, respiratory exchange ratio (RER) has been extensively used to assess adolescent substrate utilisation (Riddell, 2008). While this may be adequate during steady-state submaximal exercise, during variable intensity exercise involving near-maximal or maximal efforts, buffering of hydrogen (H^+) ions will lead to greater production of carbon dioxide (CO_2) that requires removal at the lungs, thereby over-inflating RER (Nassis *et al*., 1998).

While the relative pattern of CHO and fat metabolism with increasing exercise intensity proposed by Brooks and Mercier (1994) is observed in young people (Aucouturier *et al*., 2008), PP children and adolescents exhibit a lower RER than adults at a given relative exercise intensity (Foricher *et al*., 2003; Martinez & Haymes, 1992; Riddell *et al*., 2000; Stephens *et al*., 2006; Timmons *et al*., 2003; Timmons *et al*., 2007[a]; Timmons *et al*., 2007[b]), suggesting greater fat oxidation. This appears to be maturation-dependent, with younger boys having higher fat oxidation rates than post-pubertal boys (Stephens *et al*., 2006; Timmons *et al*., 2007[a]) and young men (Riddell *et al*., 2008). This may be due to higher intramuscular triglyceride levels, higher free fatty acid (FFA) turnover during exercise, or an underdeveloped glycolytic system (Riddell *et al*., 2008), although the latter suggestion is becoming increasingly challenged (Ratel *et al*., 2010). Endogenous CHO use is lower in adolescents compared with adults, likely due to a preferential utilisation of fat due to lower endogenous muscle glycogen levels rather than a reduced ability to utilise glycogen (Riddell, 2008; Timmons *et al*., 2007[b]), and in boys this continues even if CHO is ingested (Timmons *et al*., 2003). Development of

an adult metabolic response to exercise seems to begin at mid- to late-puberty, and is complete by the end of puberty (Stephens *et al*., 2006).

2.1.5.3 Exogenous carbohydrate

Despite a preferential utilisation of fat as a fuel source during exercise (section 2.1.5.2), young people are readily able to oxidise CHO_{exo}. While peak absolute CHO_{exo} oxidation rates appear to be lower than those of adults, probably due to the lower BM and absolute $\dot{V}O_{2peak}$ of young people (Riddell *et al*., 2000), BM-relative CHO_{exo} oxidation rates ranging from ~0.17-0.26 $g.kg^{-1}$ BM have been reported in boys aged 9-17 years (Riddell *et al*., 2000; Riddell *et al*., 2001; Timmons *et al*., 2003), which are comparable to trained, and higher than untrained, adult males (Burelle *et al*., 1999). In comparative studies with adult males, CHO_{exo} oxidation rates were ~37% greater, with the relative provision of CHO_{exo} to total energy requirement ~50% greater, in boys (Timmons *et al*., 2003). The mean contribution of CHO_{exo} to total energy requirement during exercise in boys ranges from ~16-30% (Riddell *et al*., 2000; Riddell *et al*., 2001; Timmons *et al*., 2003; Timmons *et al*., 2007[a]), and by the end of ~2 h cycle exercise can contribute ~28% to total CHO oxidation and ~25% to total energy requirement (Riddell *et al*., 2000). This is greater than the ~10-20% contribution to total energy requirement reported in adults during prolonged steady-state exercise (Burelle *et al*., 1999; Pirnay *et al*., 1995). Greater CHO_{exo} utilisation in boys has also been demonstrated to show performance benefits by significantly reducing CHO_{endo} use compared with adults (32.5 vs. 16.5% reduction in CHO_{endo} oxidation, respectively, Timmons *et al*., 2003), and increasing time to exhaustion during a cycle time-trial (TT) at 90% of PPO following a 90 min steady-state cycle (Riddell *et al*., 2001). This work is crucial, as it demonstrates that young people are able to utilise CHO_{exo} in a manner similar to adults during prolonged steady-state exercise. In females, no significant difference in CHO_{exo} oxidation rate has been observed between 12 and 14 year old girls (Timmons *et al*., 2007[b]). However, more work is required as the participants used in this study only differed slightly in maturation status, which may have masked any differences. It is

possible that gender differences in CHO_{exo} metabolism exist, possibly based on the influence of sex hormones (Aucouturier *et al*., 2008).

Mechanisms to explain the increased CHO_{exo} oxidation rate of young people are unclear but may be due to maturation-related differences in glucose transport, particularly with regard to insulin-sensitive glucose transporter type 4 (GLUT4) protein recruitment, and a greater rate of intestinal absorption of ingested CHO (Timmons *et al*., 2003), although this is doubtful (Zanconato *et al*., 1992). However, the promotion of maturation-related mechanisms suggests that CHO_{exo} kinetics in young people may be influenced by maturation status. Insulin-stimulated glucose transport from the blood appears to be higher in PP children than pubertal children or adults (Arslanian & Kalhan, 1994). This may be associated with a period of insulin resistance that occurs during puberty (Arslanian & Kalhan, 1994), and/or an inverse relationship between maturation and recruitment of GLUT4 (Dolan *et al*., 1994). Timmons *et al*. (2007[a]) demonstrated a significant reduction in the percentage contribution of CHO_{exo} to total energy expenditure during exercise between PP and EP boys (~30%) and M-LP boys (~24%) of the same chronological age. Furthermore, a highly significant, though moderate (r = -0.51), negative correlation between CHO_{exo} oxidation rate and testosterone levels was reported.

Within the available evidence, only Timmons *et al*. (2007[a]) have directly assessed maturation effects on CHO_{exo} metabolism. More work should follow in order to validate these findings, and to discover the mechanisms behind the ability of young people to utilise CHO_{exo} effectively, which seems paradoxical given their increased fat oxidation rate (section 2.1.5.2). Additionally, awareness of other confounding factors associated with research in this area should be understood, particularly when comparing studies. These include the timing and rate of CHO ingestion, CHO type, exercise intensity and duration, the procedure used to calculate CHO_{exo} oxidation, and the training and dietary status of participants.

To summarise, current research into CHO ingestion before and during prolonged exercise in young people has generated the following key findings:

- Carbohydrate ingestion during exercise can significantly increase total CHO oxidation, reduce total fat oxidation, and attenuate muscle glycogen utilisation in PP and pubertal boys.
- Carbohydrate ingestion during exercise can significantly reduce total fat oxidation in PP girls and attenuate muscle glycogen utilisation in pubertal girls.
- Exogenous CHO contributes ~15.7-30% to total energy expenditure during exercise in boys, and ~19% to total energy expenditure in girls.
- Pre-pubertal and pubertal boys may be able to oxidise CHO_{exo} at significantly greater BM-relative rates than adults.
- Ingestion of CHO during exercise can significantly improve the steady-state endurance capacity of pubertal boys.
- Biological maturation appears to influence the metabolic response to CHO ingestion, with an inverse relationship reported between biological maturation and the percentage contribution of CHO_{exo} to total energy requirement in males.

Table 2.4 Summary of research investigating substrate utilisation during exercise in young people (review articles are not summarised in this table).

Study	Participants	Protocol	Key Findings	Limitations
Barker *et al*. (2008)	8 peri-pubertal boys and 10 girls, 9.9 years 8 men and 8 women, 24.4 years	Repeated 6 min constant workrate dynamic knee flexion and extension	No significant age or gender effects for PCr kinetics at onset or offset of exercise Theoretical maximal rate of oxidative phosphorylation not influenced by age or gender Regulation of muscle O_2 utilisation is fully mature in peri-pubertal children	Assumption that phase II p$\dot{V}O_2$ kinetics reflects muscle $\dot{V}O_2$ during exercise in children
Barker *et al*. (2010)	15 boys and 18 girls, 10.7 years 8 men and 8 women, 24.4 years	Incremental knee flexion and extension test to exhaustion	No significant age or gender effects on rate of change of inorganic phosphate (P_i) /PCr against power output Increase in P_i/PCr at exhaustion significantly lower in boys than in men, and in girls than in women Muscle metabolism appears adult-like at moderate-intensity exercise, but age and gender differences in anaerobic energy turnover are present at high-intensity exercise	No notable limitations
Fleischman *et al*. (2010)	62 males and 59 females, 8-55 years	3 min submaximal leg extension exercise	PCr recovery significantly faster in younger participants, progressively slowing with increasing age Relationship between PCr recovery and age remained strong when controlling for gender, measures of physical activity, and anthropometric and metabolic parameters	Limited information on procedure to determine maximal voluntary contraction

Foricher *et al*. (2003)	14 PP boys 13 men	1 h cycle at 40-60% maximal aerobic power	During exercise, energy expenditure was significantly lower in children than in adults Fat-free mass relative energy expenditure was only influenced by intensity. Relative energy expenditure from CHO was lower in boys compared to adults Boys oxidised more lipid at 40% of maximal aerobic power than 60% of maximal aerobic power or adults at either intensity. CHO utilisation was significantly increased at 60% vs. 40% of maximal aerobic power, yet lower in boys than in men	No notable limitations
Kuno *et al*. (1995)	Control group: 29 UT males, 12.4-25 years Trained group: 14 ST boys, 12.4-14.5 years	Progressive ankle flexion exercise at 40 repetitions.min^{-1} to exhaustion	Lower glycolytic activity in children compared with adults, inferred by higher intramuscular pH at exhaustion in children. No influence of training status No significant difference in the time constant of PCr resynthesis between trained and untrained adolescents, and adults	Biological maturation in the boys was not quantified Potential inaccuracies regarding sampling different proportions of a muscle, and therefore different muscle fibre types, due to differences in muscle size Differences in end-exercise metabolic conditions between children and adults may have influenced data
Martinez & Haymes (1992)	10 PA PP girls, 9.1 years 10 A women, 24.4 years	30 min treadmill runs at 70% $\dot{V}O_{2max}$ and 7.2 km.h^{-1}	At the same relative intensity, RER was significantly lower in the girls compared to the women At the same relative intensity, RER decreased significantly during exercise in the girls but not the women Pre-pubertal girls rely more on fat metabolism	Biological maturation in the girls was not quantified Some criteria for determining a maximal test may not have been appropriate for young participants

			during moderate- to high-intensity exercise	
Riddell *et al*. (2000)	8 PA boys, 15.0 years	4 x 30 min cycling at ~60% $\dot{V}O_{2max}$, 5 min recovery between each bout Participants consumed water or CHO (3g.kg^{-1} BM) in a randomised fashion	Exogenous CHO intake: Spared CHO_{endo} depletion by 16% and fat oxidation by 45% Contributed to ~25% of the exercise energy demand Lowered RPE during exercise	Some criteria for determining a maximal test may not have been appropriate for young participants Potential delay in tracking $^{13}CO_2$ production, possibly underestimating CHO_{exo} oxidation
Riddell *et al*. (2001)	12 PA boys, 12.5 years	3 x 30 min cycling at 55% $\dot{V}O_{2max}$, 5 min recovery between each bout. Following a 10 min recovery, cycle to exhaustion at 90% PPO Participants ingested water , 6% glucose (1.5 g.kg^{-1} BM), or 3% fructose & 3% glucose (1.5 g.kg^{-1} BM) in a randomised fashion	Fat oxidation increased during all trials but was highest in the water trial Total CHO oxidation decreased in all trials and was lowest in the water trial Exogenous CHO oxidation was significantly greater in the glucose trial compared with the glucose & fructose trial Both CHO trials spared CHO_{endo} CHO and fat use to a similar extent Glucose delayed exhaustion by 25%, and glucose and fructose by 40%, compared with water	Some criteria for determining a maximal test may not have been appropriate for young participants Potential delay in tracking $^{13}CO_2$ production, possibly underestimating CHO_{exo} oxidation
Riddell *et al*. (2008)	5 PA boys, 11-12 years 9 PA men, 22-26 years	Incremental cycle test to exhaustion (longitudinal study over 3.5 years – adults assessed in two groups (n = 5 and n = 4) on one occasion only	Pre-pubertal boys had significantly greater fat oxidation rates than adults over a wide range of exercise intensities Greatest peak fat oxidation rate occurred at 11-12 years and decreased significantly throughout puberty Peak fat oxidation rates of children significantly greater than adults except for the final measurement occasion	Low participant number Some criteria for determining a maximal test may not have been appropriate for young participants Self-reporting of Tanner stages may reduce accuracy of maturation assessment Prolonged incremental cycle test may have overestimated maximal

			Exercise intensity that elicited peak fat oxidation rates non-significantly decreased throughout puberty Exercise intensity that elicited peak fat oxidation rates in children was significantly greater at all measurement occasions than adults	fat oxidation rate Limitations associated with use of indirect calorimetry to assess substrate use
Stephens *et al*. (2006)	43 males, 9-27 years 9 EP, 14 MP, 11 LP, 9 young adults	5-6 min cycle exercise at 30, 40, 50, 60 and 70% $\dot{V}O_{2max,}$ 5-10 min recovery	Greater fat use and lower CHO use in early- and mid-pubertal participants compared with late pubertal and young adult participants No metabolic differences found between early- and mid pubertal participants, or LP and young adult participants Development of an adult-like metabolic profile appears to occur between mid- to late-puberty, and is complete by the end of puberty	Some criteria for determining a maximal test may not have been appropriate for young participants Timing of La measurement after each exercise stage was not standardised within- or between-participants No information on physiological or metabolic state during recovery periods, therefore it cannot be discounted that recovery period was insufficient to prevent residual physiological changes affecting response to subsequent exercise bouts
Taylor *et al*. (1997)	41 males, 6-83 years	Plantar flexion at 0.5 Hz lifting weight of 10% of lean BM through 7 cm. Weight increased by 2% of lean BM every ~1.25 min for ~12 min	Half time of PCr recovery was and the initial rate of PCr resynthesis after exercise were fastest in the children Oxidative capacity of the calf muscle was significantly higher in the children Children had significantly higher intramuscular pH and [ADP] during exercise, associated with a very rapid PCr resynthesis rate and high maximum mitochondrial	Biological maturation status was not quantified Potential inaccuracies regarding sampling different proportions of a muscle, and therefore different muscle fibre types, due to differences in muscle size Differences in end-exercise metabolic conditions between

			capacity	children and adults may have influenced data
Timmons *et al*. (2003)	22 PA boys, 9.8-22.1 years	2 x 30 min cycle at 70% $\dot{V}O_{2peak}$, 5 min recovery. Participants ingested a 6% CHO solution or a PLA (24 m l.kg BM per trial) in a randomised fashion	For both trials, total fat oxidation was significantly higher, and total CHO oxidation significantly lower, in the children compared with adults Exogenous CHO oxidation was significantly higher, and provided a greater relative proportion of total energy, in the children compared with the adults Although CHO_{endo} use is lower in children, their relative oxidation of ingested CHO is significantly greater than adults	Self-reporting of Tanner stages may reduce accuracy of maturation assessment No information on criteria used to determine the presence of a maximal effort during $\dot{V}O_{2peak}$ test Limitations associated with use of indirect calorimetry to assess substrate use Potential delay in tracking $^{13}CO_2$ production, possibly underestimating CHO_{exo} oxidation
Timmons *et al*. (2007^a)	20 boys, 12-14 years, ranging from PP to post-pubertal	60 min cycle at 70% $\dot{V}O_{2max}$ Participants ingested a 6% CHO solution or a PLA in a randomised fashion	Exogenous CHO intake significantly decreased fat oxidation and increased total CHO oxidation across all groups Fat oxidation was greater in younger boys than older boys Exogenous CHO contributed ~30% to energy expenditure in PP and EP participants This figure fell to ~24% in the M-LP and P participants Reliance on CHO_{exo} appears particularly sensitive to pubertal status	Self-reporting of Tanner stages may reduce accuracy of maturation assessment No information on criteria used to determine the presence of a maximal effort during $\dot{V}O_{2peak}$ test Potential delay in tracking $^{13}CO_2$ production, possibly underestimating CHO_{exo} oxidation
Timmons *et al*. (2007^b)	12 PA preadolescent girls, 12 years 10 PA adolescent girls, 14 years	60 min cycle at 70% $\dot{V}O_{2max}$ Participants consumed water or a 6% CHO-E solution	Exogenous CHO intake significantly attenuated fat and CHO_{endo} oxidation in preadolescent but not adolescent girls Endogenous CHO oxidation was lower in	No information on criteria used to determine the presence of a maximal effort during $\dot{V}O_{2peak}$ test

			preadolescent girls regardless of trial Exogenous CHO oxidation rate was similar between preadolescent and adolescent participants Exogenous CHO oxidation influences endogenous substrate use in an age dependent manner but CHO_{exo} oxidation is not different between preadolescent and adolescent girls	Limitations associated with use of indirect calorimetry to assess substrate use Potential delay in tracking $^{13}CO_2$ production, possibly underestimating CHO_{exo} oxidation
Tonson *et al*. (2010)	7 PP boys, 11.7 years 10 men, 35.6 years	Finger flexion exercise for 3 min at 15% of maximal voluntary strength	Boys demonstrated significantly higher oxidative and lower PCr contribution at onset of exercise Anaerobic contribution was not different between boys and men Post-exercise PCr recovery was significantly faster in boys Maturation effects oxidative and PCr kinetics, but not glycolytic metabolism	Self-reporting of Tanner stages may reduce accuracy of maturation assessment Potential inaccuracies regarding sampling different proportions of a muscle, and therefore different muscle fibre types, due to differences in muscle size Use of PP boys and men does not provide a picture of changes in muscle energetics through the maturation process
Willcocks *et al*. (2010)	6 PA boys and 5 girls, 13 years 6 PA men and 5 women, 24 years	Two to four constant work rate knee flexion and extension exercise bouts	Time constant for PCr response to exercise was not significantly different between participants End-exercise [PCr] did not differ with age Control of oxidative metabolism at the onset of high-intensity exercise appears adult-like in 13 year old children	Potential inaccuracies regarding sampling different proportions of a muscle, and therefore different muscle fibre types, due to differences in muscle size Potential differences in training status between participants may have influence PCr kinetics Different maturation status of boys and girls may have influence the data

											Exercise intensity was only assumed to be comparable between-participants, as critical power was not assessed

PA = physically active; **PP =** pre-pubertal; **UT** = untrained; **ST** = sprint trained; **T(SS)** = trained synchronised swimmers; **EP** = early-pubertal; **MP** = mid-pubertal; **LP** = late-pubertal

2.1.6 Fatigue in young people during exercise

2.1.6.1 Introduction

It is likely that fatigue during exercise results from multiple factors acting at various sites (Noakes, 2000). However, the exact aetiologies are not fully understood (Messonnier *et al*., 2006; Noakes, 2000). This may be because the causes of fatigue are multi-faceted and synergistic (Ratel *et al*., 2006[a]), varying according to the mode, duration and intensity of exercise, muscle fibre type, contraction type, and fraction of PPO produced, and the training and health status of the participant (Little & Williams, 2007; Knicker *et al*., 2011; Messonnier *et al*., 2006).

2.1.6.2 Fatigue in young people during exercise

Articles in this section are summarised in table 2.5. Research specifically focussing on potential fatigue mechanisms during prolonged intermittent, high-intensity exercise or actual team games in young people is not currently available. Most fatigue studies have instead utilised short duration repeated cycle and treadmill sprint protocols to quantify fatigue in young people and compare this with adults. This is beneficial as it enables control over the metabolic status of the muscle and rates of resynthesis of muscle metabolites (Ratel *et al*., 2006[a]). However, identification of an appropriate resistance with which to accurately compare young people and adults is difficult due to factors such as body composition changes during growth and maturation (Ratel *et al*., 2006[a]). These protocols demonstrate that young people display less fatigue, as represented by a significantly smaller reduction in PPO and mean power output (MPO), during a given bout of relative-intensity exercise than adults (Dipla *et al*., 2009; Hebestreit *et al*., 1993; Kanehisa *et al*., 1995; Ratel *et al*., 2004; Ratel *et al*., 2002; Ratel *et al*., 2006[b]; Zafeiridis *et al*., 2005; figure 2.4). This is inversely related to age (range ~9-24 years) in males, but reaches a plateau in females at ~14-15 years (Dipla *et al*., 2009). It therefore appears that the ability to resist fatigue is negatively related to maturity during childhood and adolescence (Kanehisa *et al*., 1995; Ratel *et al*., 2006[b]; Zafeiridis *et al*., 2005). There do not

appear to be any fatigue mechanisms exclusive to young people, although ethical restrictions limit the extent of investigation into some mechanisms, particularly of a metabolic nature. The greater fatigue resistance of young people has been attributed to physiological and morphological differences that reduce the severity of commonly proposed adult fatigue mechanisms (figure 2.5).

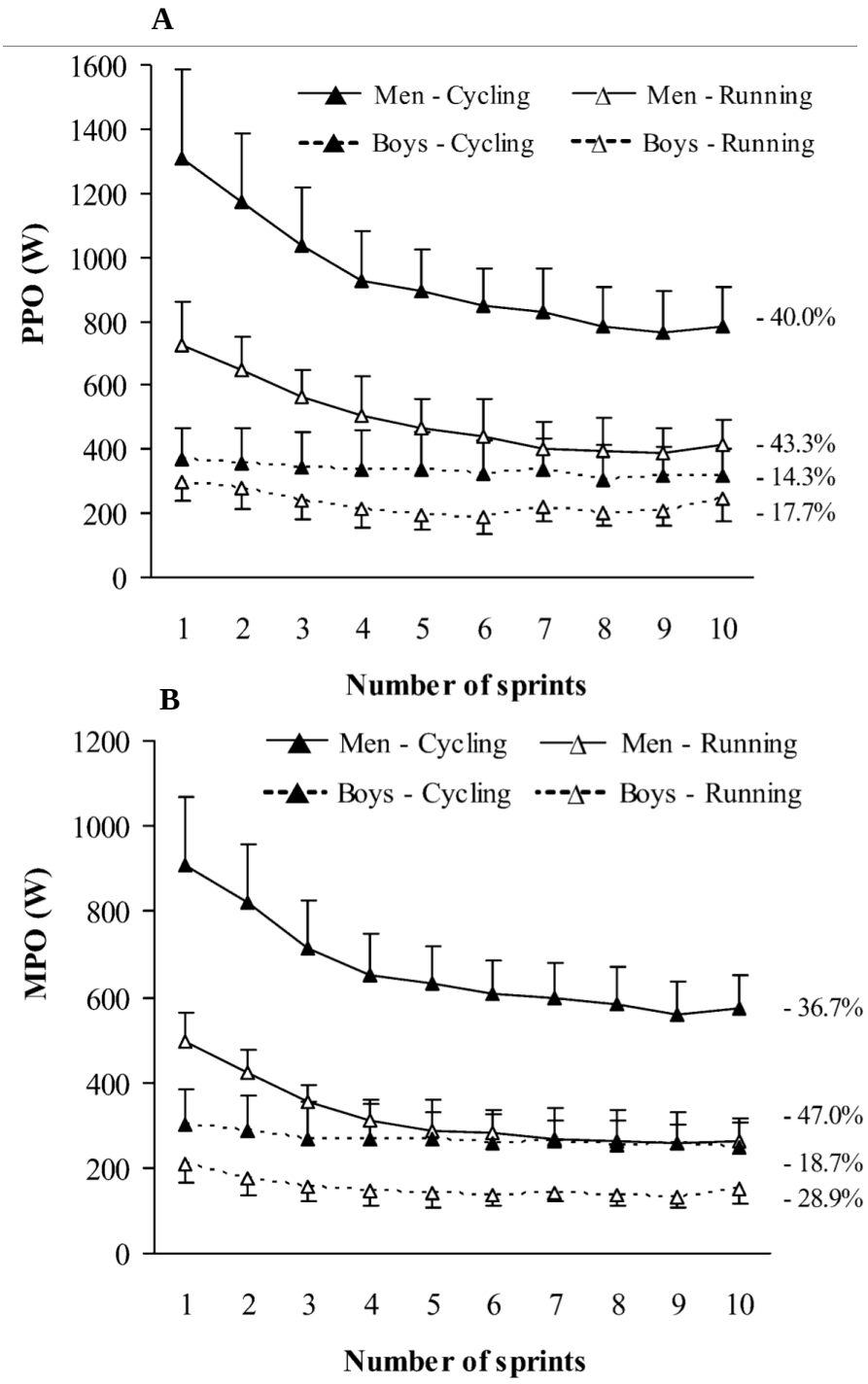

Figure 2.4 Peak power output (A) and mean power output (B) profiles during 10 x 10 s treadmill and cycle sprints separated by 15 s recovery in boys (mean age 11.7 years) and men (mean age 22.1 years). Peak power output and mean power output decreased significantly more in men compared to boys over the 10 sprints during running ($P < 0.001$) and cycling ($P < 0.001$ for peak power output, $P < 0.01$ for mean power output). From: Ratel *et al*. (2004).

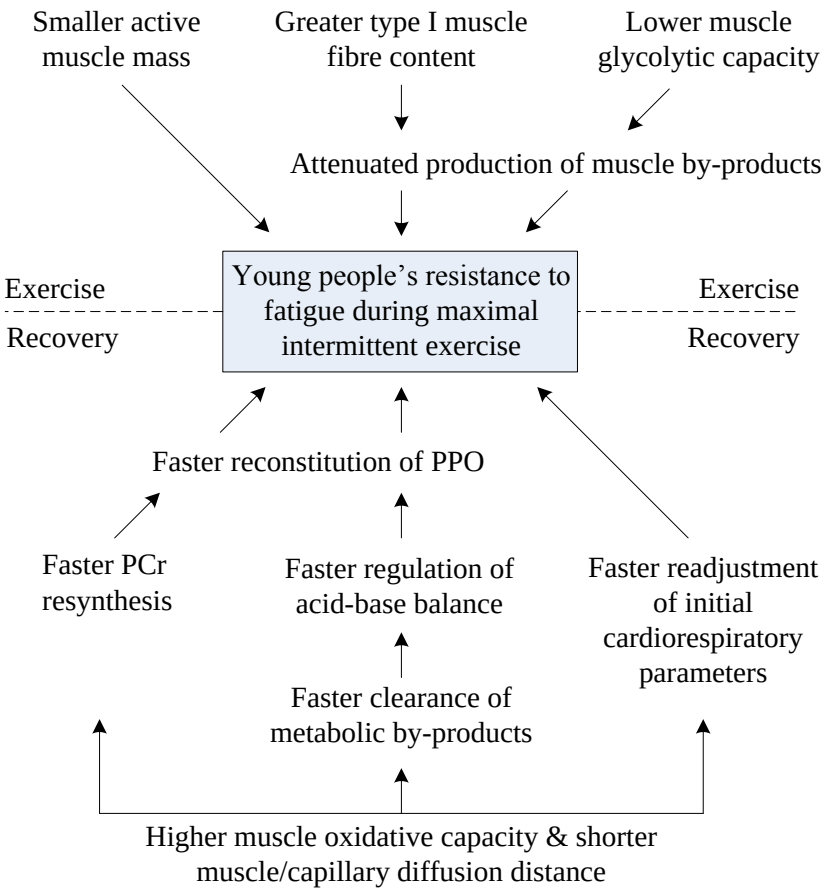

Figure 2.5 Schematic of the mechanisms proposed to explain the greater fatigue resistance of young people during repeated bouts of maximal exercise. From: Ratel *et al*. (2006[a]).

2.1.6.2.1 Fatigue resistance mechanisms during exercise

2.1.6.2.1.1 Active muscle mass

During maximal exercise and exercise at a fixed percentage of PPO, young people generate lower absolute power output (PO) than adults (Van Praagh & Doré, 2002). Fat-free mass (FFM) explains a large proportion of the difference in PO during maturation, with greater FFM associated with greater PO (Doré *et al*., 2000; 2001). Therefore, the lower FFM in young people may account, at least in part, for their greater fatigue resistance during repeated high-intensity exercise. In support, Ratel *et al*. (2004) demonstrated that the greater decline in PO in adults during repeated 10 s

cycling and running sprints (figure 2.4) was related to their higher PO relative to lower leg volume. If generation of lower absolute PO in young people does help to explain their greater fatigue resistance, it is likely that other muscle-related factors, such as morphology and energy metabolism, also contribute (Ratel *et al*., 2006[a]).

2.1.6.2.1.2 Muscle morphology

During high-intensity intermittent exercise, high type II muscle fibre content leads to greater muscle fatigue (Colliander *et al*., 1988), due to rapid depletion of PCr stores and a reduction in glycolytic rate leading to an inability to maintain adequate ATP resynthesis rates (Hultman & Greenhaff, 1991; Ratel *et al*., 2006[a]). Young people have a lower percentage of type II muscle fibres than adults (Oertel, 1988). This morphological difference could contribute to greater fatigue resistance in these participants (Ratel *et al*., 2003). However, due to potential sampling error when taking muscle biopsies (Van Praagh & Doré, 2002) further research is required to elucidate the morphological characteristics of muscle in young people. This is particularly relevant for trained young people, who may have an altered muscle fibre type distribution to untrained young people (Van Praagh & Doré, 2002). Unfortunately, this will be difficult, as the muscle biopsy is currently the main method of muscle fibre type analysis (Ratel *et al*., 2006[a]), and is ethically problematic for use in young people.

2.1.6.2.1.3 Energy metabolism

Children and, perhaps, adolescents may have an attenuated glycolytic, and enhanced aerobic, potential (Ratel *et al*., 2010). Based on this apparent difference in exercise metabolism, greater fatigue resistance in young participants may be partly related to lower accumulation of glycolytic metabolites (Ratel *et al*., 2006[a]) and faster PCr resynthesis (Ratel *et al*., 2002, section 2.1.6.2.2.1). However, lower glycolytic activation and lower blood lactate (BLa) concentration ([BLa]) in young participants is not an exclusive finding (Beneke *et al*., 2005; Beneke *et al*., 2007; Haralambie, 1982), nor is the link between increased [BLa] and fatigue (Bangsbo *et al*., 2006).

Therefore, while exercising metabolic differences could play a role in the better fatigue resistance of young people, a greater consensus on paediatric exercise metabolism is required before this can be confirmed.

2.1.6.2.2 Fatigue resistance mechanisms in recovery from exercise

2.1.6.2.2.1 Phosphocreatine resynthesis

Phosphocreatine resynthesis is dependent on oxidative metabolism (Hamilton *et al*., 1991). Children and, perhaps, adolescents may have a muscle fibre and metabolic profile more suited to oxidative metabolism (Lexell *et al*., 1992; Oertel *et al*., 1988). This may enable them to resynthesise PCr more rapidly and therefore maintain PO more effectively than adults during exercise. However, data on PCr recovery kinetics in young people is inconclusive (Barker *et al*., 2010; Fleischman *et al*., 2010). Therefore, while this may be a mechanism of increased fatigue resistance, it is unlikely to be the sole mechanism.

2.1.6.2.2.2 Clearance of metabolic by-products

High-intensity exercise in adults generates high glycolytic rates, which in turn increases production of intramuscular lactate (La) and H^+ (Ratel *et al*., 2006[a]). The associated decrease in muscle pH may contribute to muscle fatigue. Therefore, the ability to remove H^+ from muscle may be crucial. There is some evidence to suggest that young people can achieve this more rapidly than adults. Firstly, La and H^+ production may be lower due to attenuated glycolysis, although lower glycolysis in young people compared with adults is not universally accepted (Petersen *et al*., 1999). Secondly, Pilegaard *et al*. (1999) demonstrated a positive relationship between the concentration of type I monocarboxylate transporters and the proportion of type I muscle fibres. As young people have a greater percentage of type I muscle fibres, the transport and oxidation of La, and the buffering of H^+ ions, may be greater in these participants (Ratel *et al*., 2006[a]). Along with a possible greater transport of La between type I muscle fibres, young people may also have a faster diffusion of La

and H^+ from muscle into blood (Beneke *et al*., 2005), possibly due to a shorter diffusion distance between muscle and capillary (Hebestreit *et al*., 1996).

The rate of BLa disappearance is similar between children and adults following short-term high-intensity exercise (Berthoin *et al*., 2003; Dotan *et al*., 2003). This suggests that BLa disappearance dynamics would not influence the ability of young people to resist fatigue. However, Dotan *et al*. (2003) used a shorter duration test in adults to ensure a similar end-exercise [BLa] between the adults and boys. As Beneke *et al*. (2005) state, maximum [BLa] and its extravascular increase are a factor of both exercise intensity and duration; therefore, the similar rate of BLa disappearance reported by Dotan *et al*. (2003) may have been due to the different durations of the exercise tests. Indeed, Beneke *et al*. (2005) and Hebestreit *et al*. (1996) have shown that the removal of BLa following high-intensity exercise is faster in children than adults. Beneke *et al*. (2005) used a biexponential model, incorporating La exchange from muscle to blood (La appearance) and La disappearance. However, this method has been criticised in the literature (Falk & Dotan, 2006). While the effects of age on BLa removal dynamics are unconfirmed, children do have an advantage regarding La removal, as they have shorter peak BLa lag times (Dotan *et al*., 2003).

2.1.6.2.2.3 Faster readjustment of cardiorespiratory parameters

Key cardiorespiratory variables that have faster time constants of recovery in young people compared with adults following high-intensity exercise are HR, $\dot{V}O_2$, CO_2 output and ventilation (Hebestreit *et al*., 1993). The suggested mechanisms behind the faster recovery of HR in young people are highlighted in section 2.1.2. The faster recovery of $\dot{V}O_2$ in young people could be attributed to their shorter circulation time, shorter mean diffusion distance between muscle and capillary, and smaller O_2 deficit (Ratel *et al*., 2006[a]). Faster CO_2 output readjustment could relate to the lower storage of CO_2 during exercise in young people compared with adults (Armon *et al*., 1990). This could also be a mechanism for the more rapid recovery of ventilation. Clearly, a faster readjustment of cardiorespiratory variables towards baseline values

would provide a more favourable physiological platform at the beginning of the subsequent exercise bout, possibly contributing to the greater fatigue resistance of young people.

Table 2.5 Summary of research investigating fatigue and mechanisms of fatigue resistance during exercise in young people (review articles are not summarised in this table).

Study	Participants	Protocol	Key Findings	Limitations
Beneke *et al*. (2005)	39 PA males, 12.0-27 years	30 s Wingate Test	Maximal [BLa] was significantly lower in boys compared with adolescents and adults No significant differences between groups for lactate generated in the extravasal compartment related to muscle mass or movement of lactate into the blood Movement of lactate out of the blood was significantly higher in boys compared with adolescents and adults Age related differences in BLa kinetics partly reflect faster elimination of lactate from the blood	Procedures used to quantify maturation status not reported
Beneke *et al*. (2007)	20 PA boys, 11.8-16.3 years	30 s Wingate Test	Relative to muscle mass, the change in lactate and PCr concentration were not different between groups Lower [BLa] in children appears to reflect a lower relative muscle mass combined with a facilitated aerobic metabolism	Procedures used to quantify maturation status not reported
Berthoin *et al*. (2003)	9 boys, 11.3 years 8 men, 21.9 years	Incremental cycle test to exhaustion Exercise to exhaustion at 120% of maximal aerobic power	[BLa] during all stages of recovery was significantly lower in adults compared with children Following maximal exercise only, the rate of BLa recovery was significantly higher in adults	No exhaustion criteria for supramaximal exercise component

Dipla *et al*. (2009)	30 males, 11.3-24.0 years 30 females, 10.9-25.2 years	4 x 18 maximal knee flexions and extensions with 1 min rest	Fatigue resistance was greater in boys vs. teens and men, and in teens vs. men Fatigue resistance was greater in girls vs. teens and women, but not different between teens and women Fatigue resistance is negatively correlated with age and undergoes a gradual decline from childhood to adulthood in males, but in females stabilises at ~14-15 years	No notable limitations
Dotan *et al*. (2003)	14 PP boys, 11.5 years 12 men, 23.1 years Participants matched for $\dot{V}O_{2peak}$	30 s Wingate Test Adult participants also completed a shortened Wingate Test to attain [BLa] similar to that of the children	Peak [BLa] following the Wingate was significantly lower in the children compared to the adults Peak [BLa] lag time following the Wingate was significantly shorter in the children compared to the adults No significant difference was found in BLa disappearance dynamics between children and adults following the match [BLa] Wingate Test	Use of a shorter duration test in adults may have influenced BLa disappearance rates, as maximum [BLa] and its extravascular increase are a factor of both exercise intensity and duration
Hebestreit *et al*. (1993)	8 PP boys, 9-12 years 8 men, 19-23 years Participants matched for $\dot{V}O_{2peak}$	Two consecutive 30 s Wingate Tests, separated by 1, 2, or 10 min recovery	Boys recovered faster than men during all trials Suggested to reflect a lower reliance on glycolysis during the Wingate in boys	Direct measurements not made to support hypothesis on glycolysis
Hebestreit *et al*. (1996)	5 boys, 9.6 years 5 men, 24.9 years	30 s Wingate Test	At the 10^{th} min of recovery post-test, [BLa] & $[H^+]$ was significantly lower in the children compared to the adults These findings support the hypothesis of a lesser reliance on anaerobic glycolysis in children, and may explain the faster recovery	The data collected does not allow lower reliance on glycolysis to be reported as the only hypothesis for the findings Low participant numbers

			of muscle power in children compared to men	
Kanehisa *et al*. (1995)	26 boys, 14 years 27 men, 18-25 years	50 repeated constant velocity maximal knee extensions	Average decline of force over the 50 contracts was significantly greater in the men	No measurements of maturation status made
Petersen *et al*. (1999)	9 PP T(SS) girls, 10.4 years 9 pubertal T(SS) girls, 15.0 years	2 min plantar flexion at 40 & 140% maximal work capacity Participants completed the two exercise bouts in a randomised fashion	No significant difference in end-exercise muscle pH was found between participants Glycolytic metabolism in physically active children is not maturity dependent	Potential inaccuracies regarding sampling different proportions of a muscle, and therefore different muscle fibre types, due to differences in muscle size
Ratel *et al*. (2002)	11 PP boys, 9.6 years 9 pubertal boys, 15.0 years 10 men, 20.4 years	10 x 10 s cycling sprints at 50% of individual optimum force Three passive recovery durations: 30 s, 1 min, 5 min	Pre-pubertal boys sustained force production regardless of recovery duration In pubertal boys, force output decreased significantly with 30 s and 1 min recovery durations, but not 5 min recovery duration In men, force output decreased significantly with 30 s and 1 min recovery durations, and decreased slightly with 5 min recovery duration Faster recovery of force output in PP boys attributed to lower muscle glycolytic activity and higher muscle oxidative capacity allowing faster PCr resynthesis	No notable limitations
Ratel *et al*. (2004)	12 PA boys, 11.7 years 13 PA men, 22.1 years	10 x 10 s sprints, 15 s recovery Sprints completed on treadmill and cycle ergometer	Peak power output and MPO decreased significantly more in the adults over the 10 sprints in both exercise modes	No measurements of maturation status made

Ratel *et al*. (2006[b])	12 boys, 11.7 years 13 men, 22.1 years	10 x 10 s treadmill sprints Sprints were separated by 15 s or 180 s passive recovery, in a randomised fashion	With 15 s recovery, MPO, mean force output, and running velocity decreased significantly less in the children compared with the adults over the 10 sprints With 180 s recovery, MPO, mean force output, and running velocity remained unchanged in the children over the 10 sprints. In the adults, MPO and mean force output decreased significantly Children appear to maintain more easily repeated sprint performance than adults with 15 s recovery. Three-minute recovery periods are sufficient for children to complete short running sprints without fatigue Adults displayed a significantly great change in [BLa] following the 10 sprints, regardless of the recovery duration	No information provided on criteria for attainment of maximal sprints No measurements of maturation status made
Zafeiridis *et al*. (2005)	19 PA boys, 11.4 years 17 PA adolescents, 14.7 years 18 PA men, 24.1 years	Two protocols: 1. 4 x 18 maximal knee extensions and flexions, 1 min rest between sets 2. 2 x 34 maximal knee extensions and flexions, 2 min rest between sets	In protocol 1, recovery was significantly greater in boys compared with men in all sets, and in adolescents compared with men in the last two sets In protocol 2, recovery after the first set was significantly greater in the boys compared with adolescents and men Rate of recovery during anaerobic exercise is maturity dependent	No notable limitations

PA = physically active; **PP =** pre-pubertal **;** **T(SS)** = trained synchronised swimmers

2.2 Activity pattern and physiological demand of adolescent team games

2.2.1 Activity pattern of adolescent team games

Team games are intermittent, with prolonged periods of moderate- to low-intensity activity randomly interspersed with brief periods of high- and maximal-intensity work (Glaister, 2005). The characteristics of team games vary between sports, between positions and playing styles within a sport, and from one game to the next (Mujika & Burke, 2010), adding to the challenge of accurately quantifying activity patterns.

There is little information on the mean distances covered by young people during 60 min 11-a-side soccer matches on regular sized pitches. The available data reports distances ranging from 6087-6204 m in 11-14 year old males (Castagna *et al*., 2003; Castagna *et al*., 2009; Castagna *et al*., 2010). There is disagreement as to whether distance covered is influenced by playing position (Buchheit *et al*., 2010[a]; Capranica *et al*., 2001; Strøyer *et al*., 2004). Position-specific specialisation of activity patterns may be age and/or maturation-dependent, becoming more pronounced with increased age/maturity (Strøyer *et al*., 2004). Relative distance covered during soccer ($m.min^{-1}$) increases with age irrespective of playing position (Harley *et al*., 2010); however, the influence of maturation on this finding has not been elucidated, and warrants further study.

The percentage of game time spent in individual forms of activity (walking, jogging, running etc) is difficult to quantify due to inter-study differences in methodology and activity classifications. High-intensity exercise is suggested to account for 9-16% of total distance covered during a game (Castagna *et al*., 2003; Castagna *et al*., 2009; Castagna *et al*., 2010), and may be influenced by skill level (Strøyer *et al*., 2004), chronological age, and maturation (Castagna *et al*., 2003; Strøyer *et al*., 2004). The number of sprints completed per match has been reported at 33 with a mean duration of 2.3 s per sprint (Castagna *et al*., 2003), but may be position dependent. Running speed significantly increases with increasing age, and has been closely linked to

maturational influences (Mendez-Villanueva *et al*., 2011). Repeated sprint bouts (a minimum of 2 consecutive ≥ 1 s sprints interspersed with a maximum recovery of 60 s; Buchheit *et al*., 2010[b]) range from 2-42 for under 13 year old players and 0-43 for under 14 year old players, dependent on playing position. Younger players perform more and longer sprints per repeated-sprint sequence than older players (Buchheit *et al*., 2010[b]), however the influence of age and maturation is inconclusive, and likely clouded by differences in the training level and training specificity of participants (Mendez-Villanueva *et al*., 2011; Mujika *et al*., 2009; Ratel *et al*., 2006[a]). While the majority of game distance is covered in low-intensity activity, the high- and maximal-intensity components must not be overlooked as they may correspond to the most crucial events of a game, and could largely contribute to successful performance.

Significantly less total and moderate-intensity running distance may be covered during the second half of a match, suggesting the presence of a pacing strategy in young people (Castagna *et al*., 2003; Castagna *et al*., 2009; Castagna *et al*., 2010); however, this is not always found (Capranica *et al*., 2001). High-intensity running and sprinting appears more consistent across a match (Castagna *et al*., 2009; Castagna *et al*., 2010). Repeated sprint bouts fluctuate over the course of a game, which Buchheit *et al*. (2010[b]) suggested as evidence of transient fatigue in young people during soccer. However, the fluctuations may also have been due to the nature of play, i.e. the requirement for repeated sprint efforts at various stages of the match.

The above data should be considered in light of the limitations of activity profile research in team games. These are detailed by Carling *et al*. (2008), and include:

- Factors such as human error and spatial/temporal resolution issues when using video-based analysis.
- Observation of a single match failing to provide representative profile data.
- Recording activity profile data as percentage of game time or distance covered (the two methods are not interchangeable, and therefore not comparable).

- Using different inter-study classifications of activities.
- Comparing study data collected in different environments, at different stages of a season, and using players of differing skill and/or fitness levels.

More work is needed on the influence of variables including skill level, chronological age, maturation status, and playing area dimensions on the activity profile of youth soccer. Additionally, the activity profiles of youth team games other than soccer should also be studied.

2.2.2 Physiological demands of adolescent team games

2.2.2.1 Introduction

Current research on the physiological demands of adolescent team games is sparse. The following sections detail what is currently known of the physiological demand placed on adolescent team games players during small-sided games and during 30-60 min soccer matches.

2.2.2.2 Small-sided games

The literature discussed in this section used regional and elite level male soccer players and professional male rugby players with a mean age of 14.5-16.3 years. Sparse data places the mean HR of young soccer players during small-sided soccer games at 169-182 beats per min (Köklü *et al*., 2011), or 80-94.6% of maximum HR (HR_{max}; Casamichana & Castellano, 2010; Hill-Haas *et al*., 2009; Hill-Haas *et al*., 2010; Köklü *et al*., 2011). Reducing the number of players in a small-sided game while maintaining the same playing area dimensions, or increasing the playing area while maintaining the same number of players, significantly increases mean HR (Casamichana & Castellano, 2010; Hill-Haas *et al*., 2009). Furthermore, altering the rules of small-sided soccer, for example by including or excluding the offside rule, or specifying which area of the pitch attacking players must be in when a goal is scored,

can also significantly influence physiological responses (Hill-Haas *et al*., 2010). This may at least partly account for the wide variation in HR response.

There is a dearth of research on the [BLa] of young soccer players during small-sided games. Hill-Haas *et al*. (2009) reported that [BLa] was significantly influenced by player number, with values of 6.7 mmol.L^{-1} (2 vs. 2 players), 4.7 mmol.L^{-1} (4 vs. 4 players), and 4.1 mmol.L^{-1} (6 vs. 6 players) using a standardised playing area, reported. Similarly, Köklü *et al*. (2011) reported significantly greater [BLa] during 1 vs. 1 compared with 2 vs. 2, 3 vs. 3, or 4 vs. 4 games. This finding was reported despite a progressive increase in the playing area with increasing player numbers. Therefore, [BLa] during small-sided soccer games appears to be higher when fewer players are involved. However, as Hill-Haas *et al*. (2008) states, assessment of [BLa] during small-sided games is more variable than measures such as HR, probably due to the inability to control activity demands in the minutes prior to sampling.

Foster *et al*. (2010) recently published the only study to investigate the physiological responses of young rugby league players to small-sided rugby games. Mean HR ranging from 86.2-90.6% of HR_{max} was reported. No significant differences in HR response were found between the different age groups (12-13 and 15-16 years). As with small-sided soccer games, reducing player numbers from 6 vs. 6 to 4 vs. 4 while maintaining playing area dimensions elicited a significantly greater mean HR response. Conversely, modifying playing area dimensions while maintaining player numbers did not significantly alter the HR response. This could be due to the potentially different activity profile of small-sided rugby compared with soccer games. Unfortunately, no other physiological or metabolic measures were made in the study. Further research should be undertaken to broaden knowledge of the physiological responses of young people to small-sided soccer and, in particular, rugby and field-hockey, which are notably underrepresented in the current literature.

2.2.2.3 Soccer matches

The research discussed in this section used male soccer players from recreational to elite level, with a mean age range of 11.0 – 16.9 years.

2.2.2.3.1 Heart rate and oxygen consumption

Mean HR of 160-175 beats per min during outdoor 11-a-side and indoor 5-a-side soccer has been recorded (Castagna *et al*., 2007; Strøyer *et al*., 2004), with HR >170 beats per min for 88% of the first half and 80% of the second half of an 11-a-side match, and for 81% in the first half and 88% in the second half of a 7-a-side match (Capranica *et al*., 2001). As a percentage of HR_{max}, mean HR during a match has been recorded at 83.5-86.8% HR_{max}, with no significant between-halves difference (Capranica *et al*., 2001; Castagna *et al*., 2007; Castagna *et al*., 2009; Castagna *et al*., 2010). Strøyer *et al*. (2004) reported a significantly higher HR in elite compared with non-elite soccer players at the same stage of maturation. The HR values reported in the available adolescent research are similar to those of adult team games (Bangsbo, 1994[b]; Boyle *et al*., 1994). However, using HR to compare exercise intensity between adolescent and adult studies should be done with caution when it is considered that the HR of adolescents may be notably higher than that of adults during exercise at the same absolute intensity (section 2.1.2).

Mean $\dot{V}O_2$, calculated via linear regression analysis from the HR/$\dot{V}O_2$ relationship, during youth soccer is estimated at 70-80% $\dot{V}O_{2max}$ (Castagna *et al*., 2007; Strøyer *et al*., 2004). This is in agreement with adult team games (Bangsbo *et al*., 2006). Mean $\dot{V}O_2$ is significantly greater throughout a game in elite young players, and in elite young players at a later stage of maturation compared with elite young players at an early stage of maturation in the first half only (Strøyer *et al*., 2004). When interpreting this $\dot{V}O_2$ data, it should be considered that regression analysis may over-estimate actual $\dot{V}O_2$ due to factors such as heat, psychological stress, and static activity that cause HR but not $\dot{V}O_2$ to rise (Reilly, 1997). However, this error is thought to be small (Bangsbo, 1994[b]).

2.2.2.3.2 Blood lactate

Limited data for adolescent team games suggests a [BLa] of 3.1-8.1 mmol.L^{-1} during 11-a-side and 1.4-7.3 mmol.L^{-1} during 7-a-side soccer (Capranica *et al*., 2001), comparable to values reported from adult team games (Bangsbo *et al*., 2006; Duthie *et al*., 2003). This suggests a notable anaerobic component during adolescent soccer. However, [BLa] is not a valid measure of muscle La (MLa) concentration ([MLa]) or anaerobic contribution during a full game as it only reflects activities undertaken a few minutes prior to sampling, and the balance between La movement into and out of the blood (Bangsbo *et al*., 1991; Krustrup *et al*., 2006). Evidence suggests 75-80% of all La produced during exercise is oxidised (Brooks, 2000, 2007), either in adjacent, slow-twitch muscle fibres within a single muscle group (Brooks, 2007) or in the same muscle cell via intracellular La shuttles (Brooks *et al*., 1999; Hashimoto & Brooks, 2008). Therefore, this La would not be recorded in a blood sample. It is also likely that [BLa] during adolescent team games will be influenced by the timing of blood sampling, playing position, training and maturation status (sections 2.1.6.2.2.2).

2.2.2.4 Research limitations

While HR assessment is comparatively simple due to the availability of cheap, accurate and non-invasive measurement devices (see section 3.3.3), measuring metabolic responses to team games exercise is more problematic due to the lack of valid measurement tools and the issues associated with frequent measurement during a competitive field-based event. Future work must strive to develop more accurate and accessible tools for measuring metabolism. Due to these issues, many studies report variables as game-averages. Quantifying physiological demand in this way fails to realise the full complexity of the regulatory factors involved during intermittent activity (Glaister, 2005). Better field-based measurement tools must be developed and employed to expand and update knowledge of the physiological demand of team games. Specific to adolescent research, more work needs to be undertaken that quantifies different physiological demands such as substrate use,

energy cost, and fluid loss, and collects this data across a wider range of team games and with maturational influences accounted for, to enable a more comprehensive view of the physiological demands placed on adolescents during team games.

2.3 Carbohydrate ingestion during prolonged intermittent, high-intensity exercise

2.3.1 Introduction

The following sections will discuss CHO ingestion before and during prolonged intermittent exercise, laboratory and field work using prolonged intermittent, high-intensity exercise protocols, and actual team games. Focus will be placed on the influence of CHO on endurance capacity, exercise performance, and physiological and metabolic responses during these forms of exercise. The suggested mechanisms by which CHO may modulate endurance capacity and exercise performance during prolonged intermittent exercise will also be discussed. Prior to this, the key potential modulators of CHO efficacy during exercise that are relevant within the context of this thesis will be examined, along with potential oral health concerns associated with frequent ingestion of CHO solutions.

2.3.2 Modulators of carbohydrate efficacy during exercise

2.3.2.1 Fluid volume and carbohydrate composition

If CHO solutions are consumed during exercise then fluid and CHO intake are interdependent and should not be considered in isolation. Therefore, the following discussion on fluid volume, CHO concentration ([CHO]), CHO composition and solution osmolality is presented as one topic.

2.3.2.1.1 Fluid volume

Mild dehydration increases T_{core}, ratings of perceived exertion (RPE) and BM loss and impairs skill performance during team games (Edwards *et al*., 2007; Maughan &

Shirreffs, 2010; McGregor *et al*., 1999). Team games athletes should maintain adequate hydration status in order to maximise performance. This can be achieved by replacing the same amount of fluid that is lost during exercise, and is a recommended practice for adult team games athletes (Grantham *et al*., 2010; Maughan & Shirreffs, 2010). Failure to ingest an appropriate volume of fluid during exercise may prevent the athlete from maximising their performance even when ingesting CHO. More specific fluid ingestion recommendations are difficult due to the numerous factors that can influence fluid requirements, such as BM, exercise intensity, individual SR, and environmental conditions.

2.3.2.1.2 Carbohydrate concentration

Only three studies have employed different [CHO] during prolonged intermittent exercise (Murray *et al*., 1987; Murray *et al*., 1989; Welsh *et al*., 2002). Unfortunately, the use of different CHO compositions (Murray *et al*., 1987), relatively small increases in CHO ingestion between solutions (Murray *et al*., 1989), and different [CHO] within the same trial (Welsh *et al*., 2002) limit the usefulness of the results. Ingesting too little CHO may not meet energy requirements during exercise. However, consuming too much CHO can attenuate gastric emptying (GE) rate (which may already be attenuated during prolonged intermittent, high-intensity exercise; Leiper *et al*., 2005), cause gastrointestinal (GI) distress and impair intestinal fluid absorption (Leiper *et al*., 2001; Leiper *et al*., 2005; Shi *et al*., 2004).

A 5–7% CHO-electrolyte (CHO-E) solution is currently recommended for team games (Shi & Gisolfi, 1998), along with the recommendation of Jeukendrup and Jentjens (2000) for an optimal CHO intake of ~1.0–1.1 $g.min^{-1}$. However, this recommendation has not been thoroughly tested using prolonged intermittent, high-intensity exercise protocols. Carbohydrate oxidation is notably greater during prolonged intermittent, high-intensity exercise compared with continuous exercise (Christmass *et al*., 1999), suggesting that CHO ingestion requirements may be greater during intermittent compared with continuous exercise. Therefore, altering

the [CHO] of solutions ingested during prolonged intermittent, high-intensity exercise should form the basis of future study.

2.3.2.1.3 Carbohydrate composition

Carbohydrate oxidation rate depends on multiple factors, one of which is the composition of ingested CHO (Jeukendrup & Jentjens, 2000). Ingestion of multiple transportable CHO, typically glucose and fructose in a ratio of ~2:1, appears beneficial during prolonged steady-state exercise for increasing GE rate (Jeukendrup & Moseley, 2010), intestinal CHO and water absorption (Jentjens *et al*., 2006; Jeukendrup & Moseley, 2010), and CHO_{exo} oxidation rates (Jentjens *et al*., 2006; Rowlands *et al*., 2008), although the latter is not universally found (Hulston *et al*., 2009). In the only study to alter CHO composition during prolonged intermittent exercise (Murray *et al*., 1987), it was not possible to discern between effects due to changes in [CHO] and composition. Therefore, the effect of alterations in CHO composition during prolonged intermittent, high-intensity exercise should receive attention in future work.

2.3.2.1.4 Osmolality

Following ingestion of isocaloric CHO solutions of differing composition and osmolality, less than 5% of the variance in GE rate is due to differences in osmolality (Murray *et al*., 1994). Solution osmolality often increases in proportion to caloric content, indicating that the inhibition of GE originally attributed to osmolality (Coyle *et al*., 1978) may have been confused with the influence of increased caloric density (Murray, 1987). Significant negative correlations between CHO content and GE rate with ingestion of iso-osmotic CHO solutions, and positive correlations between solution caloric content and the half-time of GE, have been reported (Brouns *et al*., 1995; Calbet & MacLean, 1997). Calbet and MacLean (1997) confirmed that caloric content explained 92% of the variance in GE rate. This, along with the observation of a similar GE rate when solutions with the same [CHO] but significantly different

osmolalities are consumed (Gisolfi *et al*., 2001), suggests that CHO content and caloric density are more important than solution osmolality in modulating GE rate.

The osmolality of a CHO solution appears inversely related to the rate of water absorption in the small intestine (Hunt *et al*., 1992; Wapnir *et al*., 1991), with conflicting findings (Gisolfi *et al*., 2001; Shi *et al*., 1994) attributed to the activity and number of intestinal solute transporters, alterations in osmolality over the length of the small intestine, and solution composition (Hallback *et al*., 1991; Lambert *et al*., 1997). Increasing the [CHO] of a solution can increase osmolality, and therefore attenuate the rate of intestinal water absorption (Wapnir & Lifshitz, 1986) when [CHO] reaches ~8% (Gisolfi *et al*., 1992). This should be considered when manipulating the concentration of CHO solutions, as increasing [CHO] may allow increased absorption of CHO, but could attenuate GE rate and intestinal water absorption, and result in sub-optimal hydration status.

Carbohydrate type can also influence solution osmolality and, therefore, intestinal water absorption (Shi & Gisolfi, 1998) when [CHO] is >6% (Gisolfi *et al*., 1992). Incorporating multiple transportable CHO into a solution can offset the effect of high osmolality on intestinal water absorption (Shi *et al*., 1995) by activating a greater number of intestinal solute transport mechanisms. This could enable a high volume of CHO delivery while maintaining adequate intestinal water absorption. For a more detailed discussion on this topic, the reader is referred to the review of Shi and Passe (2010).

2.3.2.1.5 Recommendations

Future work must study the effects of altering fluid volume, [CHO], CHO composition, and osmolality, independently and in an integrated fashion. This will enable quantification of the optimal composition of a CHO-E solution for maximising intestinal fluid and CHO absorption during prolonged intermittent, high-intensity exercise.

2.3.2.2 Fluid and carbohydrate ingestion pattern

Fluid may take ~40-60 min from the time of ingestion to be transported around the systemic circulation and become physiologically useful (Coyle, 2004; Schedl *et al*., 1994). The intensity of prolonged intermittent, high-intensity exercise can attenuate GE rate (Leiper *et al*., 2005), as can the addition of CHO to a solution (Vist & Maughan, 1994). Furthermore, limited opportunities exist for fluid ingestion during team games (Clarke *et al*., 2008). Therefore, it would be interesting to investigate the effects of manipulating fluid intake regimes during prolonged intermittent, high-intensity exercise (Coyle, 2004), with and without CHO ingestion, on exercise performance and physiological responses. This would be of interest as the limited research that has investigated differences in fluid ingestion patterns during prolonged intermittent, high-intensity exercise is conflicting (Abbey & Rankin, 2009; Clarke *et al*., 2008).

2.3.2.3 Pre-exercise nutritional status

Pre-exercise nutritional status can significantly alter substrate availability, the metabolic response to exercise, and exercise performance. Ingestion of a CHO meal 3-8 h prior to prolonged (~60-290 min) moderate- to high-intensity (52-77% $\dot{V}O_{2max}$) cycling can significantly improve total work output (Neufer *et al*., 1987), TT performance (Sherman *et al*., 1989), and endurance capacity (Wright *et al*., 1991) compared to exercise in the fasting state. More sparse data also suggests that endurance capacity and repeated sprint performance during prolonged intermittent, high-intensity running is significantly enhanced following pre-exercise CHO feeding compared with low CHO intake (Bangsbo *et al*., 1992) or fasting (Little *et al*., 2009). This may be due to greater pre-exercise muscle glycogen availability (Little *et al*., 2010). Manipulating the glycaemic index of a pre-exercise CHO meal does not significantly affect sprint performance or intermittent endurance capacity during prolonged intermittent running (Erith *et al*., 2006; Little *et al*., 2009), despite increased fat oxidation rates with a low-glycaemic index meal (Little *et al*., 2009). Lack of effect may be due to the requirement for high-intensity efforts in the

intermittent protocols, which would be dependent on PCr as well as CHO metabolism (Spencer *et al*., 2005).

Increases in pre-exercise muscle glycogen concentration with CHO feeding ranging from 15-42% compared with a fasting state have been reported (Coyle *et al*., 1985; Neufer *et al*., 1987). A greater rate of CHO oxidation (assessed via RER; Neufer *et al*., 1987; Sherman *et al*., 1989; Wright *et al*., 1991) and muscle glycogen utilisation (Coyle *et al*., 1985) during exercise has also been found with pre-exercise feeding. Furthermore, Coyle *et al*. (1985) found that as muscle glycogen levels during exercise preceded by CHO feeding reached similar concentrations to that of a fasting trial, the rate of CHO oxidation was also reduced. Taken together, these findings indicate that pre-exercise CHO feeding improves exercise performance by increasing the endogenous availability of CHO and eliciting greater rates of CHO oxidation (Coyle *et al*., 1985; Neufer *et al*., 1987; Sherman *et al*., 1989; Wright *et al*., 1991). In contrast, Neufer *et al*. (1987) reported no significant difference in muscle glycogen utilisation during exercise with pre-exercise CHO feeding compared to fasting. However, the duration of the exercise protocol (~60 min) was notably different to that of Coyle *et al*. (1985; 105 min). Significant influences of pre-exercise feeding on the exercising blood glucose response appear to be transient (Sherman *et al*., 1989) or do not occur at all (Neufer *et al*., 1987; Wright *et al*., 1991). However, this may depend on the timing of the pre-exercise feeding.

Pre-exercise CHO feeding along with CHO ingestion during exercise (combined CHO feeding) has generated conflicting findings on endurance capacity and exercise performance. Chryssanthopoulos and Williams (1997) reported a significant improvement in steady-state endurance running capacity with combined CHO feeding compared with CHO intake during exercise alone or a fasting trial. Similarly, Chen *et al*. (2009) found a significant improvement in 21 km running performance with combined CHO feeding using a high glycaemic index pre-exercise CHO meal compared with CHO ingestion during exercise alone. Combined CHO feeding using a low glycaemic index meal failed to significantly improve performance compared with CHO ingestion during exercise alone. Other work has

reported non-significant trends for greater exercise performance or endurance capacity with combined CHO feeding compared with pre-exercise feeding alone (Flynn *et al*., 1989; Wright *et al*., 1991), CHO intake during exercise alone or fasting (Wright *et al*., 1991). Conversely, other authors have reported no significant improvement in cycling or running performance with combined CHO feeding compared with CHO ingestion during exercise alone (Burke *et al*., 1998; Wong *et al*., 2009). Ingesting CHO during steady-state endurance exercise can negate the proposed benefits of a pre-exercise low-glycaemic index meal by minimising potential differences in metabolic response or substrate oxidation between low- and high-glycaemic index meals (Burke *et al*., 1998; Wong *et al*., 2009).

It is difficult to establish a specific reason(s) for the different findings regarding combined CHO feeding. In the two studies that reported a significant exercise enhancement with combined CHO feeding, one study found significantly elevated blood glucose concentrations and CHO oxidation rates (Chryssanthopoulos & Williams, 1997) and one did not (Chen *et al*., 2009). In the two studies that reported trends for improvement with combined CHO feeding, one study reported significant increases in blood glucose concentration but no significant increase in RER (Flynn *et al*., 1989), and one no significant difference in blood glucose concentration or RER (Wright *et al*., 1991). Finally, the studies that reported no significant exercise enhancement with combined CHO feeding found no between-trials differences in total CHO oxidation (Burke *et al*., 1998; Wong *et al*., 2009) or CHO_{exo} oxidation (Burke *et al*., 1998). It is plausible that between-studies differences in factors including the timing and composition of the pre-exercise feeding, the composition, amount, and timing of the CHO ingested during exercise, and the exercise intensity and duration may contribute to these conflicting findings, and make a consensus on this topic difficult. However, it does appear that pre-exercise nutritional status can significantly influence substrate availability and performance during exercise, and may also alter the influence of CHO ingested during exercise. Therefore, the pre-exercise nutritional status of research participants should be considered, and must be disclosed by researchers, to facilitate clearer interpretation of study findings.

2.3.2.4 Temperature of carbohydrate solutions

Provision of cold fluid (4-5^{o}C) encourages greater fluid ingestion during exercise in mild and T_{high} conditions (Mündel *et al*., 2006) and may also enable significantly greater steady-state endurance cycling performance (Burdon *et al*., 2010) and capacity (Lee *et al*., 2008; Mündel *et al*., 2006) in the heat compared with ingestion of warm fluid (16-37^{o}C). The influence of cold fluid ingestion on steady-state cycling capacity in moderate environmental conditions appears negligible (Lee *et al*., 2008).

The studies discussed above were conducted using similar exercise protocols (steady-state recumbent or upright cycling for ~50-120 min at 50-66% $\dot{V}O_{2max}$). No work has used prolonged intermittent running protocols. Variable intensity cycling in T_{high} may significantly increase heat storage, the rate of rise in T_{core}, whole-body SR and dehydration, and significantly reduce FBF compared with steady-state cycling (Mora-Rodriguez *et al*., 2008). This, along with the current recommendation for a fluid temperature of 15-21^{o}C and the acknowledgement that preferred fluid temperature varies greatly between individuals (Sawka *et al*., 2007), provides a rationale for investigating the effects of fluid temperature during prolonged intermittent, high-intensity exercise.

2.3.3 Dental health issues with ingestion of sports drinks

Frequent ingestion of CHO-containing products before and during exercise must be balanced with a view to the potential health issues associated with this practice, particularly in young people. Commercially available sports drinks (CHO-containing solutions marketed as having the potential to enhance exercise performance) commonly contain phosphoric acid, citric acid, and sodium citrate (Cochrane *et al*., 2009). Phosphoric acid and citric acid release hydrogen into a solution, increasing its acidity (Taji & Seow, 2010). This will contribute to the pH value of 3-4 that is attributed to most sports drinks (American Academy of Pediatrics, 2011). A pH this low is associated with demineralisation (erosion) of

tooth enamel (Shaw & Smith, 1999). Several studies have shown a direct relationship between consumption of carbonated drinks and fruit juices and dental erosion in young people (Al-Majed *et al*., 2002; Johansson *et al*., 2001; Luo *et al*., 2005). Consumption of acidic fluids is now considered the leading cause of dental erosion in young people (Lussi & Jaeggi, 2006). While a causal relationship between sports drink consumption and dental erosion has been suggested (Milosevic, 1997; Milosevic *et al*., 1997; Sirmaharaj *et al*., 2002), this relationship is not always found (Mathew *et al*., 2002). Numerous intrinsic and extrinsic factors contribute to dental enamel erosion (Scheutzel, 1996; Zero, 1996), which may help to explain the non-uniform findings (Venables *et al*., 2005).

Oral saliva helps to protect dental enamel erosion by the formation of the pellicle (a protective biofilm over the tooth, protecting it from erosion; Taji & Seow, 2010) and through buffering of acidic compounds via phosphate and bicarbonate ions present in saliva (Taji & Seow, 2010). While studies in young people are required, it is known that prolonged exercise can significantly reduce saliva flow rate (Blannin *et al*., 1998), although consuming CHO beverages during exercise can attenuate this reduction (Bishop *et al*., 2000). However, it is unlikely that the protective effect of oral saliva is at its greatest during or after exercise (Venables *et al*., 2005). Furthermore, repeated consumption of sports drinks during exercise will increase the contact time between the beverage and the teeth (Venables *et al*., 2005). As consumption of sports drinks during exercise, as opposed to non-exercising periods or meals, is recommended as the most appropriate practice for young people (American Academy of Pediatrics, 2011), a significant potential for dental erosion may exist. This could be exacerbated by ingestion of sports drinks post-exercise, when the mouth is dry (Shaw & Smith, 1999).

It does appear that consumption of sports drinks may increase the risk, or prevalence, of dental enamel erosion in young people and adults. This risk may depend on factors such as the type of sports drink consumed, the method in which it is consumed (sipping, gulping, use of a straw etc), the timing and frequency of consumption and duration of exposure to the teeth, and co-ingestion of the beverage

with other foods or drinks (Taji & Seow, 2010). However, the potential risk of sports drink consumption to the dental health of young people should be seriously considered when forming guidelines for ingestion of these products in this population.

2.3.4 Early laboratory work using intermittent exercise protocols

All studies in this section were PLA controlled and are summarised in table 2.6. This initial body of work demonstrated that:

1. Consuming CHO-E solutions during prolonged intermittent exercise can significantly improve endurance capacity and exercise performance.
2. Consuming CHO-E solutions may significantly attenuate muscle glycogen utilisation during prolonged intermittent exercise.
3. Solid CHO is not significantly different to a CHO-E solution in improving endurance capacity following intermittent exercise.
4. The efficacy of CHO-E solutions during prolonged intermittent exercise may be influenced by the intensities at which exercise is performed.

However, prevalent methodological issues must be discussed prior to interpreting these conclusions.

Murray *et al*. (1987) and Coggan and Coyle (1988) were among the first to study the effects of CHO supplementation during prolonged intermittent exercise. It is unclear why Murray *et al*. (1987) conducted their study in a T_{high}. A thermoneutral trial should have been included for comparison due to the possibility of increased glycogen breakdown in T_{high} (Febbraio *et al*., 1998; Jeukendrup, 2003; Morris *et al*., 2003). Although both protocols were intermittent, neither was consistent with the activity pattern or physiological demand of intermittent exercise 'in the field' due to the nature of the recovery provided, the lack of a maximal- or high-intensity component, the structured and prolonged duration of the workloads, and the use of a cycle ergometer. However, at this early stage of study the authors may have been

more concerned with establishing a baseline of data using controlled research designs rather than maximising external validity.

Research by Murray *et al*. (1989) and Yaspelkis *et al*. (1993), while again supporting CHO supplementation, is subject to similar methodological issues. The regimented and specifically timed exercise intensities, with no maximal work and long periods of seated recovery, did not accurately reflect the physiological demand of team games. Additionally, endurance capacity and exercise performance were assessed using steady-state rather than intermittent exercise. Yaspelkis *et al*. (1993) did not provide BM-standardised volumes of the CHO or PLA solutions, meaning participants of lower BM received a larger relative CHO intake. Furthermore, muscle biopsy data was not collected during the solid CHO trial, preventing full data interpretation and hindering the ability to understand the mechanisms behind the improved endurance capacity in this trial.

The lack of improvement in intermittent endurance capacity with CHO supplementation shown by Nassis *et al*. (1998) is in contrast to the literature discussed to this point. As the authors stated, the protocol probably made large demands on muscle glycogen stores, therefore it would be expected that CHO ingestion would have improved intermittent endurance capacity. However, while the volume of fluid ingested during exercise was similar to most related work (2 $ml.kg^{-1}$ BM), the lower pre-exercise bolus (3 $ml.kg^{-1}$ BM) facilitated a lower overall CHO intake during the protocol compared with most other studies. The total amount of CHO ingested during the trial (~36 $g.h^{-1}$) was above the minimum intake of 16 $g.h^{-1}$ that is required for performance enhancement (Jeukendrup, 2004) but was notably lower than the recommended intake for maximising intestinal CHO delivery (60-70 $g.h^{-1}$; Jeukendrup & Jentjens, 2000). Furthermore, the lower volume of fluid entering the stomach may have resulted in a suboptimal rate of GE, possibly further attenuating the delivery of CHO to the intestine. Therefore, CHO may not have been systemically present in sufficient amounts to alter metabolism. This is supported by no significant between-trials difference in blood glucose concentration (with the exception of one time point), [BLa] or RER. However, due to the variable intensities

of the protocol, RER may not have been a valid method of assessing metabolism (section 2.1.5.2). It is also possible that the exercise intensity in the final part of the protocol (90% $\dot{V}O_{2max}$) was too intense, possibly causing fatigue to occur as a result of factors other than glycogen availability, such as PCr depletion (Bogdanis *et al*., 1995; Gaitanos *et al*., 1993). If so, this negates the goal of the study, and may help to explain the findings of the study being out of step with other related research.

Table 2.6 Summary of early laboratory studies on the effects of carbohydrate supplementation immediately before and during prolonged intermittent exercise on the endurance capacity, exercise performance, and physiological response of adults. All studies were placebo controlled.

Study	Participants	Protocol	Supplementation	Significant Findings	Limitations
Coggan & Coyle (1988)	7 ET(C) males	Alternating 15 min cycle at 65% and ~85% $\dot{V}O_{2max}$ to exhaustion	50% CHO (1 $g.kg^{-1}$ BM) solution at 10 min, 20% CHO (0.6 $g.kg^{-1}$ BM) solution every 30 min thereafter	Significantly higher intensity during 3rd h of exercise 18% longer time to fatigue 19% more work completed	Design of study protocol is not externally valid to demands of team sports training or competition
Murray *et al*. (1987)	13 UT males	5 x 15 min cycle at 55-65% $\dot{V}O_{2max}$, 480 rev TT (33°C)	5% glucose polymer solution 6% glucose/fructose solution 7% glucose polymer/fructose solution 2 $ml.kg^{-1}$ BM during each recovery period	Similar physiological function between trials Significantly faster TT with 6% and 7% solutions	No thermoneutral trial Design of study protocol is not externally valid to demands of team sports training or competition Small increments in [CHO] and different CHO composition makes comparison between solutions invalid
Murray *et al*. (1989)	7 UT males and 5 UT females	3 x 20 min cycle at 65% $\dot{V}O_{2max}$, 1200 rev TT	6, 8 and 10% sucrose solution 2.5 $ml.kg^{-1}$ BM before exercise and during each recovery	Similar physiological function between trials Significantly faster TT with 6% solution	Design of study protocol is not externally valid to demands of team sports training or competition

Nassis *et al*. (1998)	9 ET(R) males	Repeated 15 s run at 80% $\dot{V}O_{2max}$ for 60 min, 85% $\dot{V}O_{2max}$ for 60-100 min, 90% $\dot{V}O_{2max}$ from 100 min-exhaustion, separated by 10 s slow running	6.9% CHO-E solution 3 $ml.kg^{-1}$ BM prior to exercise 2 $ml.kg^{-1}$ BM every 20 min during exercise	Similar physiological function between trials No difference in time to exhaustion	Design of study protocol is not externally valid to demands of team sports training or competition Volume of CHO ingested may be insufficient for improving exercise capacity Intensity of exercise during final period of exercise may have been too intense
Yaspelkis *et al*. (1993)	7 ET(C) males	3.3 h intermittent (45-80% $\dot{V}O_{2max}$) cycle: - 30 min at 45% $\dot{V}O_{2max}$ - 6 x 16 min (8 min at 75%, 8 min at 45% $\dot{V}O_{2max}$) - 12 min seated rest - 5 min at 45%, 5 min at 60% $\dot{V}O_{2max}$ - 9 x 6 min (3 min at 75%, 3 min at 45% $\dot{V}O_{2max}$) - 12 min seated rest - Cycle at 80% $\dot{V}O_{2max}$ to exhaustion	Two trials: 180 ml of 10% CHO polymer solution every 20 min 25 g CHO bar every 30 min	Significantly reduced muscle glycogen use with CHO solution Significant increase in time to exhaustion in both trials No difference between liquid and solid CHO	Design of study protocol is not externally valid to demands of team sports training or competition Solutions not standardised to BM Muscle biopsies not taken during solid CHO trial

ET(C) = endurance trained cyclists; **UT** = untrained; **TT** = time-trial; **ET(R)** = Endurance trained runners

2.3.5 Team game-specific laboratory and field work

All studies discussed in this section are summarised in table 2.7. Leatt & Jacobs (1989) conducted the first study to investigate the effect of CHO ingestion before and during exercise on muscle glycogen utilisation during an exhibition soccer match. Unfortunately, an independent groups design with only five participants per group was used, placing the rigour of any statistical analyses under question. The authors attempted to control the between-groups physical demand of the game by using players from the same positions on the field. However, significant between-groups variations in exercise intensity and distance covered, and hence muscle glycogen utilisation, could have occurred due to factors including team tactics, the activity profile of the opposing team (Carling *et al*., 2008), and the score in the game. This could have influenced the reported efficacy of the CHO-E solution. However, Leatt and Jacobs (1989) attempted to control the influence of team tactics and activity profile by analysing an intra-squad match. Time-motion analysis of each player would have been useful to confirm the physical demand experienced. Solutions were administered in a single blind fashion, suggesting the potential for experimenter bias. However, the investigators had no direct contact with participants during the match. All participants consumed 0.5 L^{-1} of the CHO (35 g CHO) or PLA solution rather than a volume matched to individual BM. The authors stated post-match blood samples and muscle biopsies were taken within 20 min and 45 min of the match ending, respectively. If these tests were administered at different times between participants the reliability of the results could have been affected due to inter-participant differences in La dynamics (Tomlin & Wenger, 2002) and the onset of rapid glycogen resynthesis, particularly in the CHO group (Burke, 1997; Pedersen *et al*., 2008). While this may be speculative, it would have been beneficial to standardise the timing of these measurements. It may also have been prudent to collect some performance measures during the match to investigate whether glycogen sparing in the CHO trial facilitated any improvement or maintenance of performance compared with PLA.

In a defining study Nicholas *et al*. (1995) demonstrated, for the first time, a 33% improvement in intermittent endurance capacity when a CHO-E solution was consumed immediately prior to and during the Loughborough Intermittent Shuttle Test (LIST), a protocol specifically designed to replicate the physiological demand of soccer (Nicholas *et al*., 2000, section 3.2.2). Carbohydrate supplementation did not significantly improve sprint performance during the protocol. Solutions were prescribed relative to BM and in a double-blind, counterbalanced fashion, ensuring equal fluid and CHO (1 $g.kg^{-1}$ BM) intake across all participants. These strengths are in direct comparison to the issues highlighted in section 2.3.4.

Most subsequent research investigating CHO supplementation during prolonged intermittent, high-intensity exercise employed the LIST protocol or a slight modification of it. Almost without exception, this research demonstrates that CHO supplementation improves intermittent endurance capacity (Davis *et al*., 1999; Davis *et al*., 2000; Davison *et al*., 2008; Foskett *et al*., 2008; Welsh *et al*., 2002), or promotes metabolic alterations that infer greater capacity (Clarke *et al*., 2008; Nicholas *et al*., 1999). Improvements in intermittent endurance capacity with CHO ingestion during part B of the non-modified LIST range between 32-52% with effect sizes (ES) ranging from r = 0.21-0.80 (Nicholas *et al*., 1995; Davis *et al*., 1999; Davis *et al*., 2000). The validity of this measure should be considered, as team games athletes are rarely required to continue running to exhaustion during training or competition. However, the intermittent run to exhaustion should perhaps not be viewed as an exhaustive exercise test in the same way as an incremental $\dot{V}O_{2max}$ test to exhaustion, but rather as an assessment of the ability to maintain high-intensity exercise, which is a recognised marker of performance and fatigue during field-based team games (Carling *et al*., 2008). Despite this, the fixed workloads of most team games protocols, for example part A of the LIST, do not permit the participant to alter their workrate, therefore the influence of CHO on self-governed workrate during prolonged intermittent, high-intensity exercise cannot be quantified. Future protocols should address this. The influence of CHO supplementation on sprint performance during prolonged intermittent, high-intensity exercise is contentious,

with only three studies showing any form of improvement (Ali *et al*., 2007; Welsh *et al*., 2002; Winnick *et al*., 2005).

Not all studies support the use of CHO before and during prolonged intermittent, high-intensity exercise. Abbey and Rankin (2009) found no effect of CHO supplementation on endurance capacity or exercise performance during a prolonged intermittent, high-intensity exercise protocol. However, the different protocol and tests of capacity and performance to those discussed above, along with less frequent CHO ingestion, may help to explain this. Morris *et al*. (2003) found no performance or capacity benefits with CHO ingestion during a slightly modified LIST in 30^{o}C heat. Lack of enhancement was attributed to CHO availability not being a limiting factor in the unacclimatised participants. As the authors must have recognised this prior to the study it raises the question of why they failed to account for it, for example by acclimatising the participants. The rate of rise in T_{rec} was greatest in the CHO and PLA trials compared with the flavoured water trial. The authors suggested this was indicative of greater thermal strain due to impaired fluid delivery with ingestion of the CHO-E solution. However, this is confused when it is noted that mean T_{rec} at the end of the protocol was not significantly different between the three trials. Furthermore, impaired fluid delivery with CHO ingestion is dependent on multiple factors that were not measured in this study, and this also does not explain the similar rate of rise in T_{rec} in the PLA trial. An order effect was reported for total distance run (19% increase in trial 3 compared with trial 1), despite a randomised and counterbalanced approach to trial ordering. This may reflect a learning and/or, possibly, an acclimatisation effect across the three trials. Finally, only four of the nine participants completed the full protocol in the flavoured water trial, three in the PLA trial, and only one in the CHO trial. This invalidates any statistical tests carried out on the data. As a result of these issues, the study's findings should be interpreted with extreme caution.

Table 2.7 Summary of team-game specific laboratory and field studies on the effects of carbohydrate supplementation immediately before and during team games exercise on the intermittent endurance capacity, sprint performance, and physiological response of adults. All studies were placebo controlled.

Study	Participants	Protocol	Supplementation	Significant Findings	Limitations
Abbey & Rankin (2009)	10 T(G) males	5 x 15 min intermittent exercise: 2 x 55 m jogging at 55% $\dot{V}O_{2max}$ 2 x 55 m running at 120% $\dot{V}O_{2max}$ 2 x 55 m walking 4 x 55 m sprinting Agility and shooting tests performed during exercise	6% CHO-E solution 8.8 ml.kg^{-1} BM 30 min prior to exercise and at half-time	No difference in time to exhaustion No difference in sprint performance	Carbohydrate intake regime may not have enabled performance improvement Carbohydrate availability may not have been a limiting factor in CHO or PLA trial Blinding procedures used were not stated
Ali *et al*. (2007)	16 T(G) males	Extended LIST (part A only, 90 min duration) following glycogen depleting exercise Shooting and passing tests undertaken before and after exercise	6.4% CHO-E solution 5 ml.kg^{-1} BM prior to exercise 2 ml.kg^{-1} BM every 15 min during exercise	Significantly faster mean sprint performance during protocol	Exercise capacity was not assessed Blinding procedures used were not stated
Ali & Williams (2009)	17 T(G) males	Extended LIST (part A only, 90 min duration) following glycogen depleting exercise Passing test performed before, every 15 min during, and after exercise	6.4% CHO-E solution 8 ml.kg^{-1} BM prior to exercise 3 ml.kg^{-1} BM every 15 min during exercise	No difference in sprint performance Similar physiological function between trials	Exercise capacity was not assessed Blinding procedures used were not stated

Clarke *et al*. (2008)	12 T(G) males	Soccer-specific motorised treadmill protocol (2 x 45 min with 15 min recovery)	6.9% CHO-E solution 7 ml.kg^{-1} BM prior to exercise and during recovery (trial 1) Same total volume as trial 1 at 15 min intervals (trial 2)	Similar physiological function and metabolic response between trials Significant attenuation in gut fullness in trial 2	No performance variables measured
Davis *et al*. (1999)	10 A males	Standard LIST Double-blind design	20% CHO solution 20% CHO + BCAA solution 5 ml.kg^{-1} BM 1 h and 10 min before exercise 2 ml.kg^{-1} BM every 15 min during exercise (CHO only)	Significant increase in time to exhaustion (52% CHO, 42% CHO + BCAA) No difference between treatments	Sprint performance not assessed
Davis *et al*. (2000)	8 A males	Standard LIST Double-blind design	6% CHO-E solution 5 ml.kg^{-1} BM 10 min before exercise 2 ml.kg^{-1} BM every 15 min during exercise	32% longer time to exhaustion	Sprint performance not assessed
Davison *et al*. (2008)	10 UT males	Modified LIST: Part A for 60 min followed by incremental run to exhaustion Double-blind design	6% CHO-E solution 8 ml.kg^{-1} BM 15 min before exercise	8% longer time to exhaustion	CHO was not ingested during exercise
Foskett *et al*. (2008)	6 A(G) males	Modified LIST Part A for 90 min, and then continuously to exhaustion Double-blind design	6.4% CHO-E solution 8 ml.kg^{-1} BM prior to exercise 3 ml.kg^{-1} BM every 15 min during exercise	21% longer time to exhaustion Sprint performance unchanged Similar physiological function between trials	Low participant number

Leatt & Jacobs (1989)	10 HT(S) males	90 min outdoor friendly soccer match, 10 min interval. Treatment (n = 5) and PLA (n = 5) group	7% glucose polymer solution 0.5 L^{-1} ~10 min before match and at half-time	~39% reduction in muscle glycogen use with CHO ingestion	Low participant numbers Single-blind design Solutions not standardised to BM Variable timing of post-match blood and muscle samples No performance measurements made
Morris *et al*. (2003)	9 A males	Modified LIST in 30^{o}C heat: 5 x part A, followed by 60 s run / 60 s rest until exhaustion	6.5% CHO-E solution 6.5 $ml.kg^{-1}$ BM prior to exercise 4.5 $ml.kg^{-1}$ BM every 15 min during exercise	No difference in sprint performance or time to exhaustion Similar physiological function between trials	Participants were not acclimatised to exercise in the heat An order effect was reported for distance run Very low number of participants completed the protocol Blinding procedures used were not stated
Nicholas *et al*. (1995)	9 T(G) males	Standard LIST Double-blind design	6.9% CHO-E solution 5 $ml.kg^{-1}$ BM prior to exercise 2 $ml.kg^{-1}$ BM every 15 min during exercise	33% longer time to exhaustion Sprint performance unchanged	No notable limitations
Nicholas *et al*. (1999)	6 T(G) males	Extended LIST (part A only, 90 min duration)	6.9% CHO-E solution 5 $ml.kg^{-1}$ BM prior to exercise 2 $ml.kg^{-1}$ BM every 15 min during exercise	Sprint performance unchanged 22% reduction in muscle glycogen use	Exercise capacity not assessed Blinding procedures used were not stated

Roberts *et al*. (2010)	8 T(G) males	Bath University Rugby Shuttle Test	9% CHO-E solution 1 hr before exercise and 21, 46, and 77 min during exercise Volume ingested: 1.2 $g.kg^{-1}$ $BM.h^{-1}$	No difference in sprint performance Similar physiological function between trials	Protocol design based on activity profile data of rugby union forwards only Blinding procedures used were not stated
Welsh *et al*. (2002)	5 T(G) males and females	Modified LIST: 4 x modified part A, with a 20 min recovery between 2nd and 3rd set Modified part A: 3 x 20 m walking 2 vertical jumps at 80% maximum height 1 x 20 m sprint 3 x 20 m run at 120% $\dot{V}_{O2max}$ 2 vertical jumps at 80% maximum height 3 x 20 m jogging at 55% $\dot{V}_{O2max}$ Double-blind design Motor skill, jumping, cognitive and emotion tests undertaken before, during, and after protocol	18% and 6% CHO-E solution 5 $ml.kg^{-1}$ BM prior to exercise 3 $ml.kg^{-1}$ BM every 15 min (6% only) 5 $ml.kg^{-1}$ BM at half-time (18% only)	37% longer time to exhaustion Significantly faster sprint performance during final 15 min Similar physiological function between trials	No validity or reliability testing of modified LIST protocol
Winnick *et al*. (2005)	10 A(G) males and females	Modified LIST: 4 x 15 min modified part A, 5 min interval after set 1 and 3, 20 min interval after set 2 Modified part A (see Welsh *et al.*, 2002)	6% CHO-E solution 5 $ml.kg^{-1}$ BM prior to exercise and at beginning of 20 min interval 3 $ml.kg^{-1}$ BM beginning of each 5 min interval, 10 min into 20 min interval, and	Significantly faster sprint performance during final 15 min Similar physiological function between trials	No validity or reliability testing of modified LIST protocol

		Motor skill, jumping, force sensation, cognitive and emotion tests undertaken before, during, and after protocol	immediately after fourth set

T(G) = trained games players; **A** = active; **UT** = untrained; **A(G)** = active games players; **HT(S) =** highly trained soccer players

2.3.5.1 Protocol specificity

While the LIST has been validated as a laboratory simulation of the physiological demand of soccer play, it does have issues that limit is applicability (section 3.2.2.1 and 3.2.2.2). Therefore, while the LIST is a sound protocol for replicating the physiological demand of soccer, it should perhaps be advanced, to overcome some of its limitations. Ali *et al*. (2009) have proposed a modification to the LIST that enables participants to exercise at self-regulated intensities, which would allow quantification of the impact of interventions such as CHO supplementation on self-governed workrate. Such modifications, perhaps made in line with the most contemporary activity profile data on soccer match play, would further enhance the external validity of the LIST protocol, and hence any research that employs it. Other protocols have also been developed that require participants to run sideways and backwards, jump, and shoot a ball at a target (Russell *et al*., 2011; Williams *et al*., 2010), and that employ a 'free-running' style, i.e. without pre-determined workloads assigned to each activity (Williams *et al*., 2010). However, validity and/or reliability data is not yet available for these protocols. Clearly, contemporary research recognises the limitations of current team games simulation protocols, and is actively attempting to address them. It would also be of benefit to conduct more specific research into the influence of CHO supplementation on other adolescent field-based team games, for example rugby and field-hockey. This could be achieved by perhaps utilising appropriate versions of protocols such as the Bath University Rugby Shuttle Test described by Roberts *et al*. (2010).

Good external validity of a laboratory exercise protocol still does not guarantee that an intervention will demonstrate the same outcome when used in the field. Despite the inherent difficulties of conducting scientifically rigorous research during field-based team games (section 2.3.5), it would be beneficial to determine the effects of CHO ingestion when adolescent team games players participate in actual team games competition. However, as Bishop (2008) argues, the efficacy of an intervention should first be established in a controlled environment, as if the intervention is not

beneficial there, it is unlikely to be beneficial in the more uncontrolled, random environment of the 'real-world' setting.

2.3.6 Physiological and metabolic responses to prolonged intermittent exercise with carbohydrate ingestion

Ingesting CHO does not appear to influence directly $\dot{V}O_2$, HR, T_{core}, plasma volume (PV), and BM or fluid loss during team games (Ali & Williams, 2009; Ali *et al*., 2007; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Ostojic & Mazic, 2002). Some authors have reported a significantly lower HR throughout prolonged intermittent, high-intensity exercise with CHO ingestion (Davis *et al*., 1999; Davis *et al*., 2000), attributed to a trend for better maintenance of PV. However, other work has reported non-significantly lower PV losses with CHO supplementation without a significant alteration in HR response (Nicholas *et al*., 1999). The significantly higher $\dot{V}O_2$ with CHO supplementation reported by Ali *et al*. (2007) and Coggan and Coyle (1988) could relate to an augmented work rate. Ostojic and Mazic (2002) found a significantly lower BM loss after a soccer match with CHO ingestion, attributed to larger sweat and urine losses in the PLA trial. However, SR and urine loss were not measured in the study. Furthermore, the limitations associated with using BM loss as a measure of hydration status should be considered (Maughan *et al*., 2007). Extraneous factors associated with conducting the study in the field, such as possible differences in exercise intensity both within- and between-teams, as well as differences in the timing of BM measurement between players before, during and after the match, may also have contributed to the different BM losses, independent of CHO intake.

Carbohydrate ingestion alters the metabolic response to team games exercise, with a significant increase in blood glucose concentration found either periodically, (Ali & Williams, 2009; Ali *et al*., 2007; Backhouse *et al*., 2007; Bishop *et al*., 1999; Bishop *et al*., 2002; Foskett *et al*., 2008; Nassis *et al*., 1998; Nicholas *et al*., 1995; Roberts *et al*., 2010), or throughout, exercise (Davis *et al*., 1999; Murray *et al*., 1989; Ostojic & Mazic, 2002). Studies that have not recorded increased blood glucose concentration

may have been hampered by infrequent blood sampling opportunities (Leatt & Jacobs, 1989; Zeederberg *et al*., 1996) and/or a small sample size (Leatt & Jacobs, 1989; Nicholas *et al*., 1999). Significant increases in blood insulin concentration may also occur with CHO supplementation (Clarke *et al*., 2008; Coggan & Coyle, 1988; Foskett *et al*., 2008; Yaspelkis *et al*., 1993), but this is not consistently observed.

Significantly greater CHO oxidation rates are recorded with CHO ingestion (Ali & Williams, 2009; Ali *et al*., 2007; Clarke *et al*., 2008; Coggan & Coyle, 1988; Yaspelkis *et al*., 1993), along with a strong trend for attenuated blood FFA levels (Ali & Williams, 2009; Clarke *et al*., 2008; Coggan & Coyle, 1988; Davis *et al*., 1999; Davis *et al*., 2000; Foskett *et al*., 2008; Yaspelkis *et al*., 1993) and fat oxidation rates (Ali & Williams, 2009; Clarke *et al*., 2008), although this is not consistent (Ali *et al*., 2007; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Ostojic & Mazic, 2002; Roberts *et al*., 2010). Nassis *et al*. (1998) found no increase in CHO oxidation rates with CHO intake, but this may be due to protocol issues (section 2.3.4). Respiratory exchange ratio appears to be significantly higher during prolonged intermittent exercise when CHO is ingested (Coggan & Coyle, 1988; Murray *et al*., 1989; Yaspelkis *et al*., 1993). Ali *et al*. (2007) did not find a between-trials difference in RER during the LIST, despite a higher rate of CHO oxidation in the CHO trial. This highlights the issues associated with using RER to quantify metabolic responses to intermittent exercise (section 2.1.5.2).

The BLa response to prolonged intermittent exercise is largely unaffected by CHO ingestion (Ali & Williams, 2009; Ali *et al*., 2007; Coggan & Coyle, 1988; Davis *et al*., 1999; Davis *et al*., 2000; Foskett *et al*., 2008; Murray *et al*., 1987; Murray *et al*., 1989; Nicholas *et al*., 1995; Ostojic & Mazic, 2002; Roberts *et al*., 2010; Welsh *et al*., 2002), except at exhaustion where it has been reported to be significantly higher (Nassis *et al*., 1998; Yaspelkis *et al*., 1993). This may reflect an ability to continue exercising to a higher intensity before reaching exhaustion. However, if this is the case, [BLa] is not a reliable marker of this phenomenon, as numerous studies have

described enhanced intermittent endurance capacity without a significant increase in [BLa].

2.3.7 Mechanisms of enhancement with carbohydrate supplementation during prolonged intermittent exercise

2.3.7.1 Intermittent endurance capacity

It appears that CHO supplementation extends intermittent endurance capacity by reducing endogenous muscle glycogen utilisation in the first ~75 min of exercise (Davis *et al*., 1999; Davis *et al*., 2000; Nicholas *et al*., 1995). Nicholas *et al*. (1999) seemed to confirm this by showing a combined 22% reduction in type I and II muscle fibre glycogen utilisation with CHO ingestion during 90 min of the LIST. This was attributed to factors including CHO_{exo} oxidation sparing endogenous stores, and greater activity of the pyruvate dehydrogenase (PDH) complex due to hyperinsulinaemia and lower [BLa]. Other studies support the hypotheses of CHO-mediated muscle glycogen sparing and/or glycogen resynthesis during prolonged intermittent exercise due primarily to observations of increased blood glucose and/or blood insulin concentrations (Davis *et al*., 1999; Davis *et al*., 2000; Morris *et al*., 2003; Nicholas *et al*., 1995; Yaspelkis *et al*., 1993). However, only Yaspelkis *et al*. (1993) measured muscle glycogen concentration, finding a 25% greater concentration at the end of exercise in type I muscle fibres in the CHO trial. This suggests sparing of muscle glycogen rather than its synthesis during exercise, which is suggested to occur in type II muscle fibres (Nicholas *et al*., 1999). However, the evidence for synthesis of glycogen during exercise is extremely sparse. Coyle *et al*. (1986) found no significant difference in the pattern of muscle glycogen utilisation during prolonged steady-state cycling at ~70% $\dot{V}O_{2max}$ with CHO ingestion during exercise compared with a non-CHO PLA trial. Furthermore, the additional ~1 h of exercise completed in the CHO trial before exhaustion was undertaken with very little reliance on muscle glycogen. This suggests that oxidation of CHO from other sources, namely blood glucose, can extend exercise capacity independent of muscle glycogen status, at least during steady-state cycling at the intensity used by Coyle *et*

al. (1986). Supporting evidence for greater PDH activity with CHO supplementation is lacking. However, work into the mechanisms of CHO efficacy should continue when it is considered that only a small amount of CHO_{exo} may be oxidised, or made available for oxidation, in the first hour of exercise regardless of whether CHO exerts an ergogenic effect (Jeukendrup *et al*., 1997) or not (McConnell *et al*., 2000).

The potential influence of CHO on perceptual responses to exercise may enable enhanced intermittent endurance capacity (Ali *et al*., 2007; Backhouse *et al*., 2007; Utter *et al*., 2007). While this hypothesis requires more work, as the relationship between CHO ingestion, RPE and performance during team games exercise has not been clearly established, it does appear that CHO may modify the perception of effort during prolonged intermittent, high-intensity exercise.

The significantly lower HR reported by some authors (Davis *et al*., 1999; Davis *et al*., 2000) during prolonged intermittent, high-intensity exercise when CHO is ingested (section 2.3.6) infers reduced stress on the cardiovascular system and an ability to exercise at a higher intensity for a given HR, and may possibly contribute to improved intermittent endurance capacity. However, the common observation that CHO exerts no influence on PV or HR during team games exercise suggests that altered HR response is not a consistent ergogenic mechanism of CHO supplementation. Furthermore, Ali *et al*. (2007) found a trend for a higher HR with CHO ingestion during the LIST; however, this may have been due to faster sprint times with CHO supplementation (section 2.3.7.2).

2.3.7.2 Sprint performance

Improved sprint performance during prolonged intermittent, high-intensity exercise following ingestion of a CHO-E solution has been attributed to maintenance of blood glucose levels (Ali *et al*., 2007; Welsh *et al*., 2002) which may enable greater muscle and cerebral metabolism (Ali *et al*., 2007), thereby maintaining central nervous system (CNS) function and allowing better maintenance of PO, or muscle glycogen sparing (Winnick *et al*., 2005). These hypotheses are debatable as blood glucose

concentration did not reach hypoglycaemic levels in the CHO or PLA trial in the studies of Ali *et al*. (2007) or Welsh *et al*. (2002), and muscle glycogen levels were not measured by Winnick *et al*. (2005). It should be stated that the participants in the Ali *et al*. (2007) study began exercise with depleted glycogen stores. This may explain the improved sprint performance with CHO supplementation in this study, as short duration maximal-intensity exercise can be attenuated if muscle glycogen levels fall below a critical threshold (~200 $mmol.kg^{-1}$ dry weight (d.w.), Bangsbo *et al*., 1992; Bangsbo *et al*., 2006). Therefore, ingestion of CHO may have provided a sufficient supply of glucose to the muscle to enable greater sprint performance in the glycogen depleted state compared with PLA. However, the extent of glycogen depletion was not quantified; therefore this hypothesis is speculative. Furthermore, Ali and Williams (2009) reported a significant attenuation of sprint performance during the LIST in the CHO and PLA trials when participants began exercise in a glycogen depleted state. However, the extent of glycogen depletion was not stated. This also does not explain the improved sprint performance documented by Welsh *et al*. (2002) or Winnick *et al*. (2005), as participants in these studies were not glycogen depleted prior to exercise.

When glycogen availability is not compromised, PCr concentration ([PCr]) and its rate of resynthesis rather than CHO availability is more related to short-duration sprint performance (Greenhaff *et al*., 1994), perhaps helping to explain the lack of effect of CHO on sprint performance in most studies. However, it should be considered that while PCr availability is the determining factor when short sprints are interspersed with adequate passive recovery, during prolonged intermittent, high-intensity exercise participants are required to jog, run and walk between each sprint. In this situation, PCr resynthesis may not be complete enough to contribute fully to each sprint, particularly in the later stages of exercise, although this will likely depend on the duration of the sprints, and the duration and mode of recovery between sprints (Abt *et al*., 2011; Spencer *et al*., 2005). If this were the case, other substrates, notably CHO and fat, would become more prevalent fuels during the sprints (Spencer *et al*., 2005). Therefore, CHO supplementation may be important for maintaining sprint performance during the later stages of team games exercise. This may be

particularly pertinent when pre-exercise muscle glycogen stores are not optimal (Ali *et al*., 2007), but may also help to explain the findings of Welsh *et al*. (2002) and Winnick *et al*. (2005) who reported a significant improvement in sprint performance in the later stages of exercise only. It may also help to explain the non-significant between-trials difference in sprint performance observed in most studies. However, this requires further investigation.

2.3.8 Carbohydrate gel ingestion during exercise

The literature discussed in the above sections used CHO in solution form as the intervention. However, CHO ingested in the form of a gel has become a widely accepted practice by both professional and recreational athletes (Patterson & Gray, 2007; Pfeiffer *et al*., 2009). When CHO is ingested in a solution, fluid and CHO ingestion are inextricably linked (Pfeiffer *et al*., 2009). The requirement for a high CHO intake would necessitate a high fluid intake, perhaps above that which is recommended, or which the athlete would typically consume (Pfeiffer *et al*., 2009). The use of CHO solutions, and the unaccustomed ingestion of high fluid volume, are both associated with GI distress during exercise (Lambert *et al*., 2008; van Nieuwenhoven *et al*., 2005). Additionally, the relative amounts of fluid and CHO in a solution can have a significant bearing on intestinal water and CHO absorption (section 2.3.2.1). Ingestion of CHO in gel form would enable a dissociation between CHO and fluid intake. Therefore, CHO gel ingestion may facilitate a more flexible CHO ingestion strategy suited to differences in exercise demand, environmental conditions, portability, and personal preference / tolerance (Burke *et al*., 2005; Campbell *et al*., 2008; Pfeiffer *et al*., 2009). Despite the widespread use and potential practical benefits of CHO gel ingestion during exercise, comparatively little scientific research has been conducted (Saunders *et al*., 2007).

One of the first studies to investigate CHO gel ingestion during exercise was reported in abstract form only by Brooks *et al*. (2002). The authors reported a significant increase in blood glucose concentration during a track running session followed by a

5 km run when a CHO gel was ingested compared with a water PLA or solid CHO. Unfortunately, performance data for the 5 km run was not reported.

Earnest *et al*. (2004) reported the first significant enhancement of exercise performance with ingestion of a CHO gel. Participants completed a 64 km cycle TT significantly faster when either a low or high glycaemic index CHO gel was ingested compared with a PLA gel. Similarly, Campbell *et al*. (2008) reported a significant enhancement in 10 km cycle TT performance following an 80 min cycle at 75% $\dot{V}O_{2peak}$ with ingestion of a CHO gel compared with a water PLA. The CHO gel improved TT performance to the same extent as a CHO solution at the same BM-relative CHO ingestion rate. There are concerns regarding treatment blinding in this study. A water PLA was used, therefore participants would likely have been aware of when they were in the PLA trial due to the potential differences in consistency, colour, taste and texture between water and a CHO gel and solution. Furthermore, blinding between a CHO gel and CHO solution would be extremely difficult due to the different consistencies of these two mediums.

Burke *et al*. (2005) reported a negligible effect of CHO gel ingestion on half-marathon running performance. However, an ~2.4% BM loss was reported during the run in both the CHO and PLA trials, and an order effect was present for performance time. These issues may have negated the effect of the gel. Three participants reported performance-affecting GI issues with the CHO gel. However, Burke *et al*. (2005) stated that the participants habitually avoided CHO ingestion during training and competition, which may explain this finding. Pfeiffer *et al*. (2009) reported low mean GI discomfort scores during 16 km outdoor running with CHO gel ingestion. Despite this, ~10-20% of participants did encounter significant GI distress, indicating that individualised gel feeding strategies may be required (Pfeiffer *et al*., 2009).

Recently, the first study investigating the effect of a CHO gel during prolonged intermittent, high-intensity exercise reported a 45% improvement in intermittent endurance capacity compared to a PLA solution (Patterson & Gray, 2007). This

improvement is comparable to that seen when consuming CHO solutions during the same or similar protocol (Foskett *et al*., 2008; Nicholas *et al*., 1995; Welsh *et al*., 2002). Patterson and Gray (2007) used a PLA solution, matched for taste, colour, and temperature, as a comparison to the CHO gel. Despite matching for these criteria, it is possible that participants would still have been aware of whether they were consuming a gel or a solution, due to the different consistencies of the products. Reporting of blinding statistics would have been useful to validate the success of the single-blinding procedures used. Furthermore, depending on the amount of information the participants were provided with as to the aims and/or expectations of the study, the use of a PLA solution could have raised a significant potential for experimenter bias and/or participant expectancy that may have greatly impacted the results. Although initial findings regarding CHO gels and prolonged intermittent, high-intensity exercise are positive, more research is clearly required.

Elevations in blood glucose concentration when CHO gel is ingested before and during exercise (Brooks *et al*., 2002; Campbell *et al*., 2008; Patterson & Gray, 2007) lead some authors to conclude that the exercise enhancement mechanisms of CHO gels are similar to those described for CHO solutions (section 2.3.7). However, elevated blood glucose concentration during exercise with CHO gel ingestion is not consistently observed (Burke *et al*., 2005; Earnest *et al*., 2004), irrespective of whether or not exercise performance or endurance capacity is enhanced. Viscosity can influence the rate of GE (Malmud *et al*., 1982), with the addition of gel-forming fibres to CHO solutions reported to slow GE (Smith *et al*., 1993). Alterations in GE rate may explain between-studies differences in blood glucose concentration with CHO gel ingestion. However, Leiper *et al*. (2000) found a faster rate of GE of a gel-forming CHO compared with a low viscosity CHO solution. No significant differences in blood glucose or insulin concentrations were found between the two treatments. However, it is important to note that this was a non-exercising study.

Pfeiffer *et al*. (2010) specifically investigated the oxidation of CHO_{exo} supplied by a CHO gel and a CHO solution of equal composition and energy content during prolonged cycling. Exogenous CHO oxidation showed a similar time-course

between trials, with no significant differences in peak CHO_{exo} oxidation rate or oxidation efficiency. Therefore, CHO_{exo} oxidation from a gel appears similar to that from a solution, and provides support for similar exercise enhancement mechanisms between these two CHO mediums. However, further work into the influence of CHO gel ingestion on muscle glycogen utilisation and variables related to the perception of exercise demand is required to develop a greater understanding of mechanistic processes.

The motivation behind research into CHO gel ingestion during exercise is to provide understanding in an area of sports nutrition that is widespread but not well supported by scientific research. Additionally, the potential of CHO gel ingestion to provide alternative and more flexible methods of CHO provision during exercise makes study in this area valuable. Currently, the available evidence is not strong enough, either in volume or scientific rigour. Specific to prolonged intermittent, high-intensity exercise, the only available study contains a crucial methodological limitation that prevents confident interpretation of the findings. For these reasons, further study into CHO gel ingestion during prolonged intermittent, high-intensity exercise is required.

2.3.9 Summary

Most early research investigating CHO ingestion during prolonged intermittent exercise was subject to methodological limitations that restricted both its scientific rigour and its applicability to actual sporting activity. The development of prolonged intermittent, high-intensity exercise protocols enabled a more focussed investigative approach to this topic. The key findings from discussion of the literature in section 2.3 are:

1. Carbohydrate ingestion significantly improves intermittent endurance capacity in adults. Possible mechanisms include muscle glycogen sparing during the first ~75 min of exercise, although evidence is conflicting; and altered effort perception during exercise.

2. Carbohydrate ingestion has a negligible effect on sprint performance in adults during team games. Carbohydrate efficacy may depend on endogenous muscle glycogen availability.
3. Carbohydrate ingestion does not directly alter physiological responses to prolonged intermittent, high-intensity exercise, with any alterations likely due to an augmented work rate via CHO supplementation. Carbohydrate supplementation usually increases blood glucose and insulin concentrations either periodically or throughout exercise, increases CHO oxidation rates and RER, and attenuates blood FFA levels and fat oxidation rates.
4. It has been suggested that a 5-7% CHO–E solution containing multiple transportable CHO, Na^+, and with an osmolality of 250-370 $mOsm.kg^{-1}$ may be optimal before and during prolonged intermittent, high-intensity exercise. However, very little subsequent work has attempted to test these recommendations, as well as other potential modulators of CHO efficacy, during this form of exercise.
5. Carbohydrate gel ingestion can significantly improve intermittent endurance capacity during prolonged intermittent, high-intensity exercise. However, research is sparse, and the only available study has methodological limitations. Therefore, further work is required.

2.4 Research questions and hypotheses

The aim of this thesis is to investigate the influence of CHO ingestion immediately before, and during, prolonged intermittent, high-intensity exercise on the endurance capacity, sprint performance, and physiological responses of adolescent team games players. To fulfil this aim, the following research questions and hypotheses have been formulated:

Question 1: Does ingestion of a carbohydrate-electrolyte solution immediately before and during prolonged intermittent, high-intensity exercise influence the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players?

Hypothesis 1: Ingesting a carbohydrate-electrolyte solution will significantly increase the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 2: Ingesting a carbohydrate-electrolyte solution will not significantly influence the repeated 15 m sprint performance of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 3: Ingesting a carbohydrate-electrolyte solution will not significantly influence the physiological response, as measured by HR, SR and BM loss, of adolescent team games players during prolonged intermittent, high-intensity exercise.

Question 2: Does the carbohydrate concentration of a solution ingested immediately before and during prolonged intermittent, high-intensity exercise influence the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players?

Hypothesis 1: Carbohydrate concentration will significantly influence the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 2: Carbohydrate concentration will not significantly influence the repeated 15 m sprint performance of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 3: Carbohydrate concentration will not significantly influence the physiological response, as measured by HR, SR and BM loss, of adolescent team games players during prolonged intermittent, high-intensity exercise.

Question 3: Does ingestion of a carbohydrate gel immediately before and during prolonged intermittent, high-intensity exercise influence

the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players?

Hypothesis 1: Ingesting a carbohydrate gel will significantly increase the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 2: Ingesting a carbohydrate gel will not significantly influence the repeated 15 m sprint performance of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 3: Ingesting a carbohydrate gel will not significantly influence the physiological response, as measured by HR, SR and BM loss, of adolescent team games players during prolonged intermittent, high-intensity exercise.

Chapter 3: General Methods

Chapter Aims

This chapter provides a detailed description of the participant recruitment processes and inclusion criteria, data collection methodologies, protocols, equipment, measurements and calculations that were consistent across all studies. Discussion of the validity and reliability of key test protocols, and rationales for the selection of specific study procedures, have been included to support and justify their inclusion within the thesis. Worked examples of calculations used to produce study data have been incorporated. Finally, a summary of the statistical analyses consistent across all studies is included.

3.1 Participants

All studies in this thesis were granted full ethical approval by the University of Edinburgh, Moray House School of Education Ethics Committee prior to participant recruitment and data collection (appendix A3.1). Adolescent males and females participated in the studies, subject to fulfilment of the following inclusion criteria:

1. To be between 12-14 years old for the duration of the study.
2. Regularly participating in competitive soccer, rugby or field hockey to at least club level. This was defined as training on a weekly basis and taking part in all competitive matches, subject to health / injury status and the selection choices of the team coach.
3. Free from muscle and joint injury for the duration of the study.
4. Free from medication that influences the ability to exercise for the duration of the study.

Inclusion criterion one was included to reduce the influence of biological maturation on performance, as this variable is difficult to assess accurately both from a procedural and ethical perspective (appendix 1). Criterion 2 was constructed to ensure participants were familiar with the type of exercise undertaken in the studies,

thereby enabling a more representative physiological response, and to increase the likelihood of participants successfully completing the protocol. Criteria 3 and 4 were included to ensure parity across trials, remove possible sources of data invalidity, and enhance the health and safety of the participants.

Recruiting young people to participate in exercise science research is challenging from an ethical, moral, consensual, and logistical perspective (appendix 1). The recruitment process began by contacting, and then visiting, local schools and sports clubs. An information pack containing a cover letter (appendix A3.2), detailed parental project information sheet (appendix A3.3), permission slip (appendix A3.4), and stamped addressed envelope was provided to all interested individuals. If parents gave permission for their child to participate, they posted the signed permission slip to the principal investigator. Parents were then contacted by telephone and arrangements made for the participant to visit the laboratory. Prior to testing, parents were given the opportunity to question the principal investigator regarding any aspect(s) of the study. When satisfied, they signed a parental informed consent form (appendix A3.5).

During the participants' first visit to the laboratory, the relevant study was described and a summary information sheet provided (appendix A3.6). Participants were continually encouraged to ask any questions and voice any concerns that they may have had. A child assent form was then signed (appendix A3.7), followed by completion of a medical questionnaire (appendix A4.1), approved by the University of Edinburgh Ethics Committee, to identify any medical issue(s) that may have exposed the participant to excess risk during the studies. The recruitment and retention procedures employed in this thesis are summarised in figure 3.1.

To minimise the influence of external factors on performance, each participant was required to adhere to the following procedures:

1. To refrain from heavy exercise for at least 48 h before each test.

2. To complete a food diary (appendix A4.2) for 24 h prior to the first experimental testing session, and to replicate this diet for 24 h prior to subsequent testing sessions to standardise pre-test substrate and hydration levels. In subsequent sessions, the completion and replication of this diary was verbally confirmed for each participant. Participants were not requested to complete the diary in sufficient depth to enable a subsequent dietary composition analysis, as this would have placed greater stress on extremely time-pressured participants and their parents, potentially reducing adherence to the dietary record, and retention of participants through the full study. Related adult research did not complete dietary analyses.
3. To wear the same clothing for all testing sessions.
4. To undertake all testing sessions at the same time of day, or as near to this as possible.

Specific participant numbers and physical characteristics for each study are stated in the relevant chapter.

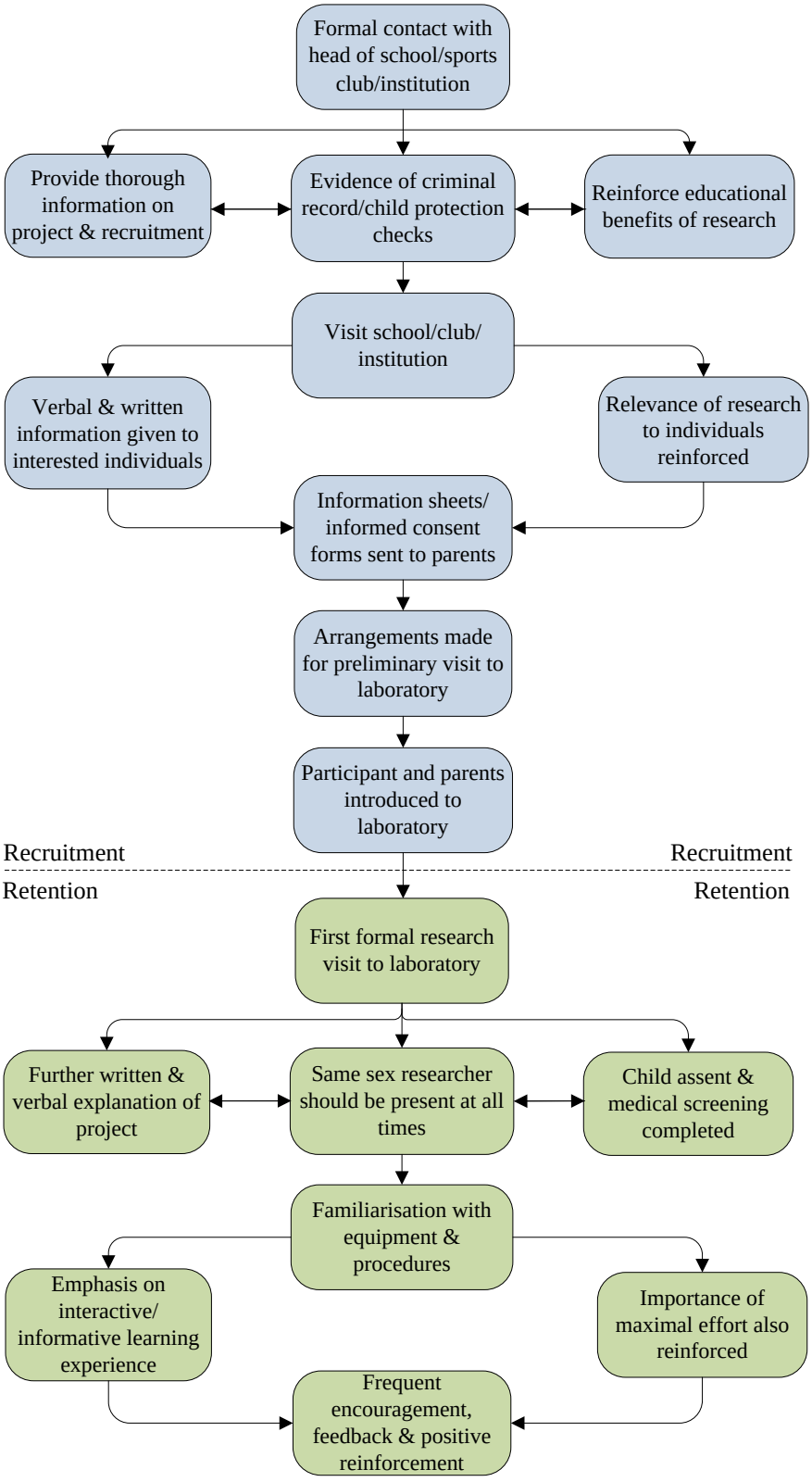

Figure 3.1 The participant recruitment and retention procedures employed in this thesis. These procedures are not exhaustive, and may differ between studies. Adapted from: Nevill (2003).

3.2 Test protocols

All studies in this thesis were conducted using a randomised, counterbalanced, double-blind research design. Within-studies, all trials were separated by a minimum of three, and maximum of seven, days to prevent fatigue or alterations in fitness levels from influencing the results.

3.2.1 Peak running velocity test

The peak running velocity (V_{peak}) test was used to set individualised running speeds for the main exercise protocol (section 3.2.2). This is opposed to the more common calculation of speed based on percentage of $\dot{V}O_{2max}$, and is believed to more accurately reflect physical demand during team games (Bangsbo, 1994[a]; Sirotic & Coutts, 2007). The physiological responses to incremental maximal treadmill running and free-range running have been reported to be similar (Crouter *et al*., 2001). A full explanation of the test aims and procedures was provided, after which participants voided and urinated if necessary, then fitted a portable HR monitor (section 3.3.3) and sat quietly for 5 min to ensure a resting state was achieved. This was confirmed by observation of a stable HR.

The participants all had different levels of experience of running on motorised treadmills (section 3.3.2). Therefore, prior to undertaking the V_{peak} test all participants walked at a self-selected speed on the treadmill for 2 min, then completed the first four levels of the V_{peak} test along with the procedure for stepping off of the running belt, as described below, to familiarise themselves with the treadmill. This meets published guidelines for the undertaking of treadmill familiarisations (Lavcanska *et al*., 2005). Prior to this, the participant was informed that in order to avoid having to speak during the V_{peak} test, they would use a system of signals to communicate their level of comfort to the investigator. These signals were:

1. A ‘thumbs up’ sign - the participant is feeling comfortable and able to continue.
2. A thumb held out, parallel to the floor – the participant is feeling uncomfortable, and test termination may be imminent.
3. A ‘thumbs down’ sign – the participant has reached exhaustion and wishes to terminate the test immediately.

During the familiarisation, these signals were practised to ensure the participant was comfortable with their use. The validity of the test was improved by this familiarisation, as the participants were able to execute a more natural running technique from the onset of the test, attenuating the impact of reduced running economy on $\dot{V}O_2$, HR, and running speed. It also acted as a standardised warm-up for each participant. Following the familiarisation, participants sat quietly for 5 min to recover and allow any excess anxiety to dissipate before starting the test.

Based on pilot work, the V_{peak} test was adapted from Marino *et al*. (2004) to start at 8 $km.h^{-1}$ at a gradient of 1% for one-minute and increase by 0.5 $km.h^{-1}$ in one-minute increments until the participant could not continue despite strong verbal encouragement. The investigator clearly informed participants of any impending changes in running speed, providing a 5 s countdown prior to making alterations. This was to prevent participants being taken by surprise at any speed changes, which may have influenced their performance or been hazardous to their safety. The protocol changes were implemented as adolescents generally have lower absolute running speeds compared to adults, and increasing the speed by 1 $km.h^{-1}$ each minute may have underestimated V_{peak} by causing participants to terminate the test when they could have continued running at an interim speed. Prior to the test, the participant was informed that as soon as they had given the ‘thumbs down’ signal, they should place both hands on the side rails and lift their feet off the running belt and on to the stationary sides of the treadmill. At this point, the investigator stopped the belt. This was to prevent participants falling forwards or backwards by remaining on the running belt as it rapidly stopped. Immediately following test termination, the belt was set to a speed that enabled each participant to walk

comfortably, and they were instructed to rejoin the belt and walk for 5 min to facilitate recovery. A maximal effort was confirmed by observation of subjective symptoms of fatigue (facial flushing, unsteady gait, heavy sweating, hyperpnoea) and attainment of a HR ≥ 195 beats per min (Armstrong, 2007). Subjective symptoms of fatigue were observed in all participants across all studies. On a total of four occasions throughout the three studies, a HR ≥ 195 beats per min was not achieved. Maximum HR on these occasions was not more than 5 beats per min below the criterion value of 195 beats per min. Maximal HR of young people has a notable inter-individual variation, reflected by standard deviations of 5-12 beats per min (Armstrong, 2007). Therefore, based on consistent observation of subjective fatigue symptoms, a maximal effort was accepted on these occasions. Peak running velocity and HR_{max} were calculated as the highest treadmill velocity maintained for 30 s and the highest 5 s average, respectively. Participants' $\dot{V}O_{2peak}$ was not assessed, as $\dot{V}O_2$ was not an outcome measure of the studies. Therefore, assessing $\dot{V}O_{2peak}$ would have placed the participants under greater stress and required additional familiarisation sessions, potentially affecting participant recruitment and retention, while adding very little in terms of physiological knowledge to the studies. Data from the V_{peak} test was collected using the form in appendix A4.3.

Following a 10 min seated recovery, participants performed 15 min of the primary exercise protocol to familiarise themselves with the required running speeds and the data collection procedures.

3.2.2 Loughborough Intermittent Shuttle Test

Prior to commencing the LIST, participants' sat quietly for 5 min and then undertook a standardised 10 min warm-up, based on the general descriptions of Nicholas *et al.* (1995):

1. 5 min treadmill run at 60% $V_{peak.}$
2. 5 x 20 m striding interspersed with 20 m slow jog.

3. Ten repetitions of the following dynamic stretches: arm swings, trunk rotations, leg swings, hip rotations. Pictorial representations and descriptions of these stretches are in figure 3.2 and 3.3.

Arm swings: The extended arm is rotated in a full circle in a vertical plain around the shoulder joint.

Trunk rotations: The torso is rotated from a neutral position to the right, and then through neutral to the left in a fluid motion. This constitutes one repetition. The lower body remains static throughout the movement.

Figure 3.2 Pictorial and written description of the two dynamic upper body stretches undertaken by participants during the pre-exercise warm-up for each study.

Leg swings: The leg is swung forwards from standing in a kicking action, and is then swung behind the body in a fluid motion. This constitutes one repetition. The upper body remains static.

Hip rotations: The hip is flexed and then horizontally abducted, before being horizontally adducted and lowered in a fluid motion. This constitutes one repetition. The upper body remains static.

Figure 3.3 Pictorial and written description of the two dynamic lower body stretches undertaken by participants during the pre-exercise warm-up for each study.

Following the warm-up, participants sat and were provided with the appropriate pre-exercise bolus (see individual chapters). They were instructed to consume the solution within a 5 min time-period, but not to consume it too quickly. To assist in this, the principal investigator informed them when each minute had elapsed. As this research was the first to investigate CHO ingestion during prolonged intermittent,

high-intensity exercise in young people, it was decided to keep the solution ingestion regime the same as the majority of previous adult work, i.e. ingestion of a larger pre-exercise solution bolus followed by smaller, consistent volumes during exercise (Davis *et al*., 1999; Nicholas *et al*., 1995; Nicholas *et al*., 1999). This was done in order to investigate the influence of CHO using an ingestion regime that has demonstrated enhancements in exercise performance.

The LIST was conducted over 20 m on a level, firm vulcanised rubber floor and consisted of a set pattern of intermittent exercise performed in four 15 min blocks separated by 3 min seated recovery (part A), followed by an intermittent run to exhaustion (part B). A schematic of the full protocol is in figure 3.4. The speed of the walking shuttles was initially set at 1.54 $m.s^{-1}$ (Morris *et al*., 2003), but as a result of pilot work, was amended for the young participants in this thesis. The order of each cycle of exercise in part A was as follows:

1. 3 x 20 m at walking pace (1.3 $m.s^{-1}$).
2. 1 x 20 m sprint.
3. 3 x 20 m at running speed corresponding to 55% $V_{peak.}$
4. 3 x 20 m at running speed corresponding to 95% $V_{peak.}$

Part B consisted of single 20 m shuttles alternating between running speeds corresponding to 55 and 95% V_{peak} until exhaustion. Exhaustion was defined as the inability to maintain the required pace for three consecutive shuttles at the higher running velocity. Prior to each participant's first testing session, an audio compact disc was programmed with a series of clearly audible beeps. These single beeps were programmed to sound at appropriate intervals to ensure the walking, jogging and cruising shuttles in part A, and the jogging and cruising shuttles in part B, were completed at the correct speed based on each participants individual running speeds. The participants were required to reach the end of each shuttle as the beep sounded. Throughout the protocol, participants were immediately informed if they deviated from the required pace, and were encouraged to adjust their speed to re-gain the correct pace. This was usually accomplished by the end of the next shuttle. If at any

time participants arrived at the end of a shuttle in advance of the pacing signal they were required to wait until they heard the signal before commencing the next shuttle. This was to prevent possible confusion, and inaccurate exercise intensity, due to participants running out of synchronisation with the signals. Participants were verbally encouraged to perform maximally during all sprints and during part B, and were not made aware of their performance during any part of the LIST. Upon reaching exhaustion in part B, participants walked slowly for 2 min and then sat quietly for 5 min. If participants needed to urinate at any time from the onset of the protocol until completion of the measurement of post-exercise BM, they did so into a measuring jug, with this volume incorporated into the BM loss and SR calculations (section 3.3.7). Participants were encouraged to urinate during the 3 min recovery periods, where possible. The need to urinate during the protocol occurred on five occasions throughout all three studies.

Throughout each trial, the investigator ensured participants placed at least one foot on or over the line marking each end of the 20 m distance, and continually informed participants about the characteristics of each subsequent exercise phase (i.e. walk, sprint, jog, cruise). A cone was placed 8 m before the start line, in the centre of the runway. Participants always ended their single sprints by crossing the start line, and were instructed to stop at this cone and immediately turn and jog back across the start line to begin the jogging phase. This was to prevent premature deceleration during the sprint, prevent participants stopping too quickly following a sprint and risk injury, and to standardise, within- and between-participants, the distance and time between ending each sprint and beginning the jog.

The LIST protocol used in these studies was adapted from Nicholas *et al*. (1995) and normally consists of five sets of part A followed by part B. However, adolescents normally play team games for a shorter time than adults, for example ~60 min in soccer compared to the standard adult duration of 90 min (Ekblom, 1986). Therefore, in these studies part A of the LIST was repeated four times (60 min), followed by part B. Data was collected using a standardised form (appendix A4.4).

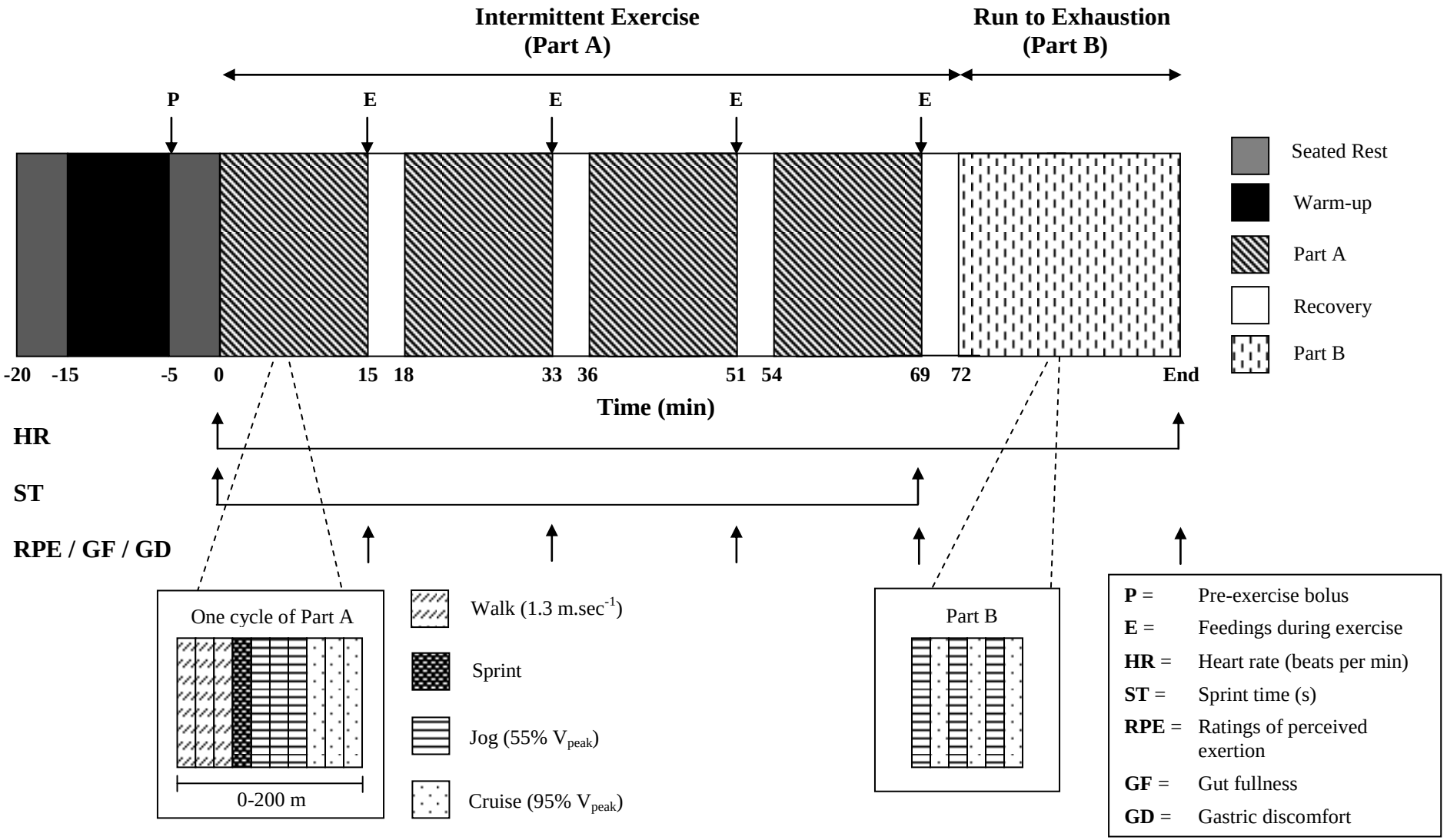

Figure 3.4 Schematic of the modified Loughborough Intermittent Shuttle Test protocol. Adapted from Nicholas *et al*. (1995).

3.2.2.1 Validity and reliability of the Loughborough Intermittent Shuttle Test

The LIST was developed as a controlled laboratory protocol to simulate activity patterns during a soccer game (Nicholas *et al*., 1995) and has become a popular method of assessing the physiological and metabolic responses to team games. Nicholas *et al*. (2000) reported that the HR, [BLa] and fluid loss responses to the LIST in trained adult male soccer players were similar to values reported during soccer matches. There also appears to be good agreement between distance covered, sprinting frequency, and mean $\dot{V}O_2$ recorded during the LIST and soccer match play (Bangsbo *et al*., 1991; Bangsbo *et al*., 2006; Mohr *et al*., 2003). Magalhães *et al*. (2010) reported significantly higher HR during a soccer match compared with the LIST; however, issues associated with the activity profile and physiological analyses of field-based team games (section 2.2.2.4) should be considered when comparing the LIST with actual soccer play.

Nicholas *et al*. (2000) calculated the relative time spent in each exercise mode during part A of the LIST. Walking accounted for 48.1%, sprinting 3%, recovery 4.9%, jogging 24.7%, and cruising 19.3% of total exercise time. This works out as 77.7% of total time spent in low-intensity activity and 22.3% of total time in high-intensity work. Therefore, the LIST makes a greater relative high-intensity demand compared to soccer (Bangsbo *et al*., 2006). Nicholas *et al*. (2000) attribute this to the fact that soccer is self-paced with players ensuring they complete 90 min, whereas the LIST is a structured protocol where participants are not permitted to slow down unless they become exhausted (section 3.2.2.2).

The LIST does not include soccer activities such as jumping, sideways or backwards running, simulated tackling, or activities in possession of a ball. Nicholas *et al*. (2000) acknowledge this, stating that these activities will increase energy expenditure and therefore must be considered when making comparisons between the LIST and actual match play data.

The LIST appears to have good test-retest reliability in adults, both in terms of performance and physiological measures. In the only specific validity and reliability study of the LIST, Nicholas *et al*. (2000) assessed the reliability of sprint times during part A and time to exhaustion during part B. The 95% limits of agreement for sprint times and run times were -0.14 to 0.12 s and -3.19 to 2.16 min, respectively, indicating that these performance measures are reproducible within these limits. No between-trials differences were found for any physiological or metabolic variables.

3.2.2.2 Fixed versus self-selected workload protocols

Exercising to exhaustion at a fixed workload is a common laboratory protocol. This allows for valid analysis as all participants can undertake the protocol at the same relative intensity, thereby enabling objective quantification of the chosen outcome measures. However, these protocols show poor reliability (coefficient of variation of 2.8-31% and 17-40% for cycle to exhaustion at 80 and 85% $\dot{V}O_{2max}$, respectively; Jeukendrup *et al*., 1996[b]; McLellan *et al*., 1995), and do not mimic normal competitive situations (Schabort *et al*., 1998).

The fixed workloads of the LIST enable it to be structured as a valid representation of the known activity profile of soccer in terms of, for example, the percentage of time spent in specific movement classifications, number of sprints completed, and the overall physiological demand (section 3.2.2.1). Also, the intermittent run to exhaustion in the LIST appears to have better reliability than that of steady-state fixed workload protocols (section 3.2.2.1), perhaps due to its shorter duration. However, it would be appropriate to question the validity of this part of the protocol with regard to performance during team games, where the end-point of the exercise is known. This is important given the body of work suggesting that individuals may adopt subconscious 'pacing strategies' during exercise with a known end-point, in order to reach that point without encountering significant homeostatic disturbance (Tucker & Noakes, 2009). However, as mentioned in section 2.3.5, the intermittent run to exhaustion should perhaps not be viewed as an exhaustive exercise test *per se*,

but as an assessment of the ability to maintain high-intensity exercise, which would still qualify it as an endurance capacity test.

While using a fixed-workload intermittent protocol does enable objective quantification of interventions such as CHO supplementation, it does not allow the participant to perform exercise as they would in the field, such as employing a pacing strategy and/or reducing the intensity of exercise, distance covered, and the frequency of high-intensity activity as exercise progresses. Therefore, the true nature, or scope, of the influence of interventions such as CHO supplementation during team games exercise may be masked by using these fixed-workload protocols. For example, it is logical to suggest that interventions shown to improve intermittent endurance capacity at the end of the LIST may also elicit other improvements, such as the ability to maintain a higher exercise intensity earlier in the protocol. However, this would not be apparent due to the fixed nature of the LIST. It would be interesting for future work to employ modifications to the LIST such as those suggested by Ali *et al*. (2009) to test this hypothesis.

3.2.3 Biological maturity status

Mirwald *et al*. (2002) developed gender-specific multiple-regression equations to determine the timing of an individual from peak height velocity (PHV; biological maturity offset). The equations use measurements of chronological age, standing height, sitting height, leg length, and BM. For a worked example of the male prediction equation, see table 3.1. A negative offset represents the number of years the individual is from reaching PHV, with a positive offset representing the number of years since the individual reached PHV. Therefore, maturity offset can be used as a categorical variable (pre- or post-PHV) or a continuous measure of maturity (Mirwald *et al*., 2002). The male and female equations yield a coefficient of determination of $r^2 = 0.89$, with Mirwald *et al*. (2002) stating that biological maturity offset can be estimated to within ± 1 year 95% of the time. These equations have been used to quantify maturity in two recent studies (Fairclough & Ridgers, 2009; Wickel *et al*., 2009) as an alternative to the methodologically and ethically problematic skeletal and sexual methods (appendix 2). Prediction of age at PHV

(APHV) is non-invasive, does not require longitudinal measurements, and appears both accurate and reliable. Additionally, it provides a maturity benchmark that exists in males and females, thereby enabling between-gender comparisons (Baxter-Jones *et al*., 2005). For these reasons, and the issues with the other measures discussed in appendix 2, the prediction equations of Mirwald *et al*. (2002) were used to quantify biological maturity in this thesis.

Table 3.1 An example of predicting years from peak height velocity for a boy using the prediction equation of Mirwald *et al*. (2002).

Maturity offset = -9.236 + (0.0002708 x leg length and sitting height interaction) + (-0.001663 x age and leg length interaction) + (0.007216 x age and sitting height interaction) + (0.02292 x weight to height ratio)

Age: 12.4 years
Height: 152 cm
Weight: 42.0 kg
Sitting Height: 80.2 cm[a]
Leg Length: 71.8 cm[b]
Leg length and sitting height interaction: 71.8 x 80.2 = 5758.36
Age and leg length interaction: 12.4 x 71.8 = 890.32
Age and sitting height interaction: 12.4 x 80.2 = 994.48
Weight by height ratio: (42/152) x 100 = 27.63

Maturity offset = -9.236 + (0.0002708 x 5758.36) + (-0.001663 x 890.32) + (0.007216 x 994.48) + (0.02292 x 27.63)

Maturity offset = -1.35 years from PHV

Age at PHV = 12.4 years + 1.35 = **13.75 years (average maturer)**

[a] Sitting height measured by assessing participants height while sitting fully erect on an adjustable stadiometer (section 3.3.1)
[b] Leg length calculated by subtracting participants sitting height from their standing height (Mirwald *et al*., 2002)

3.3 Equipment and measurements

3.3.1 Height and body mass

Height was measured in centimetres using a freestanding adjustable stadiometer (Seca, model no. 2251821009, Germany) during each participant's preliminary visit

to the laboratory. Dry nude BM was measured in kilograms using a digital scale (Seca Digital, model no. 7052321009, Germany) during the preliminary visit, prior to the warm up, and on completion of the 5 min post-exercise recovery period in all trials. Participants urinated and voided prior to all BM measurements.

3.3.2 Motorised treadmill

A motorised treadmill (Ergo ELG 55, Woodway, Germany) was used for various aspects of the experimental testing (see sections 3.2.1 & 3.2.2). The treadmill operated over a speed range of 0-40 $km.h^{-1}$ and a gradient range of 0-30% (Operating Manual, Woodway, USA). Due to the different construction of the running belt compared to other commercially available treadmills, the belt did not require adjustment or calibration and was accurate to ± 0.1 $km.h^{-1}$ (Operating Manual, Woodway, USA). However, regular safety and calibration checks were performed as part of routine laboratory procedures.

Speed and gradient controls, as well as an emergency stop button, were located on the side of the treadmill for participants' use. However, a control panel was also located on a table at the left hand side of the treadmill. This allowed the investigator to control the speed and gradient of the treadmill, and stop the belt if required, without being in direct contact with the treadmill or participant but remaining in close proximity. On all occasions, the investigator controlled the speed and gradient of the treadmill with participants instructed not to use the controls, and only to use the emergency stop button if required.

3.3.3 Heart rate

Heart rate was recorded using a short-range telemetry system (HR monitor), consisting of an adjustable chest strap transmitter and a wristwatch receiver (Polar RS400, Polar Electro Oy, Finland). The HR monitor was capable of detecting HR ranging from 15-240 beats per min, with a stated accuracy of ± 1% or 1 beat per min (Polar RS400 Operating Manual, Polar Electro Oy, Finland). While the accuracy of

HR monitors using chest strap transmitters ranges from ± 1 beat per min across the monitors functional range to ± 6 beats per min 95% of the time (Godsen *et al*., 1991; Macfarlane *et al*., 1989), these devices are accepted as accurate and valid tools for measuring HR during exercise (Achten & Jeukendrup, 2003). Furthermore, while validity and reliability data for the specific HR monitor used in this thesis is not currently available, it is unlikely that HR monitors would have regressed in their accuracy or reliability since this earlier work was carried out.

Participants' HR data was stored in the memory of the wristwatch receiver, and upon completion of each testing session was downloaded onto a computer software program (Polar ProTrainer 5, Polar Electro Oy, Finland). From this program, the raw data was transferred into an excel spreadsheet for analysis. Mean HR was recorded every 5 s during the V_{peak} test and the LIST protocol, in line with Welsh *et al*. (2002). Most previous research involving CHO supplementation during the LIST recorded HR at 15 s intervals (Davis *et al*., 2000; Davis *et al*., 1999; Morris *et al*., 2003; Nicholas *et al*., 1995; Nicholas *et al*., 1999); however, this may have resulted in reduced data sensitivity and an inability to detect certain trends or fluctuations within the data.

3.3.4 Sprint time

All sprints completed by each participant during the LIST were measured using two sets of wireless infrared single-beam photoelectric cells (Speed Trap 2, Brower Timing Systems, Utah, USA). The centre of the lenses of the photoelectric cells were set at a height of 82.5 cm from the ground. Pilot work determined that this height minimised both the risk of participants breaking the beam with a limb as opposed to their torso, and of breaking the beam twice as they passed through it, which would lead to inaccurate timing of the sprint. As the participant sprinted through the first set of cells, they broke an infrared beam, which sent a radio transmission to a hand-held timer, triggering the stopwatch. When the participant sprinted through the second set of cells, another infrared beam was broken, sending a radio transmission to stop the stopwatch. The investigator then recorded the sprint

time and reset the timer. Sprints were timed to the nearest 1/100 s, in line with previous related work (Ali *et al*., 2007; Davis *et al*., 2000; Davis *et al*., 1999; Morris *et al*., 2003; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Welsh *et al*., 2002). During the experimental trials, participants were encouraged to remain in time with the pre-programmed audio sounds (section 3.2.2) so that upon reaching the end of the runway they did not have to wait in a stationary position before sprinting. However, they were informed that in the event of arriving at the end of the runway in advance of the audio signal, they should remain standing stationary and, upon hearing the signal, sprint forwards without initially rocking backwards.

3.3.5 Children's Omnibus Walk/Run Scale of Perceived Exertion

Adult RPE scales may not be suitable for use with young people (Groslambert & Mahon, 2006). Some young people may not have developed the ability to understand intensity descriptors associated with adult scales, may have difficulty assigning words or phrases to numbers (Robertson *et al*., 2000), and may be better able to interpret illustrative depictions of stages of effort (Roemmich *et al*., 2006). As a result, the Children's Omnibus (OMNI) Scale of Perceived Exertion (appendix A4.5) was developed (Utter *et al*., 2002). The Children's OMNI Scale contains pictorial and verbal descriptors of effort along a 0-10 scale. The pictorial representations are interchanged depending on the exercise mode, i.e. a cyclist for cycle ergometry, and a runner for treadmill and shuttle running (walk/run scale). The OMNI walk/run scale used in this thesis has been validated in 6-13 year old males and females during submaximal treadmill walking and running up to ~93% HR_{max} (Roemmich *et al*., 2006; Utter *et al*., 2002), with strong correlations between RPE and HR (r = 0.90 – 0.93), and $\dot{V}O_2$ (r = 0.90 – 0.94; Roemmich *et al*., 2006). Response linearity cannot be inferred beyond the peak exercise intensity used in these studies, and it would be beneficial for future work to assess validity at a full range of intensities up to and including exhaustion.

3.3.5.1 Experimental use

During the preliminary testing session, the OMNI walk/run scale was explained. To ensure parity and consistency, instructions for use of the scale were read to each participant. These instructions were taken from the original OMNI walk/run scale validation paper (Utter *et al*., 2002), in line with Roemmich *et al*. (2006). An undifferentiated, i.e. whole body, RPE assessment was used. The instructions read to each participant are shown in figure 3.5.

Definition: How tired does your body feel during exercise?

Instructions: 'We would like you to walk and then run on a treadmill for a little while. Every minute it will get a little faster. Please use the numbers on this picture to tell us how your body feels when on the treadmill. Please look at the person at the bottom of the hill who is just starting to walk (point to the left pictorial). If you feel like this person when you are on the treadmill you will be "not be tired at all." You should point to a 0 (zero). Now look at the person who is barely able to run on the treadmill on the top of the hill (point to the right pictorial). If you feel like this person when you are running you will be "very, very tired." You should point to a number 10 (ten). If you are somewhere in between "not tired at all" (0) and "very, very tired" (10), then point to a number between 0 and 10.

We will ask you to point to a number that tells how your whole body feels including your legs and breathing. Remember, there are no right or wrong answers. Use both the pictures and words to help select the numbers. Use *any* of the numbers to tell how you feel when on the treadmill.'

Figure 3.5 Instructions for the use of the Children's Omnibus Walk/Run Scale of Perceived Exertion that were read to each participant during the preliminary visit in each study.

At this point, the participant was given the opportunity to ask any questions they had concerning the use of the scale. Following this, the low and high points of the scale

were anchored. The participant was requested to establish cognitively a perceived intensity of exertion in line with that visually depicted by the figure at the bottom (low anchor, rating 0) and top (high anchor, rating 10) of the scale (Robertson *et al*., 2000; Utter *et al*., 2002).

During the participants first experimental testing session, the OMNI walk/run scale was reviewed. The participant was informed that, despite the different nature of the protocol, the use of the scale was the same, and when requested, the participant should use the pictures and words to select a number representing how their whole body felt at that moment in the exercise bout. Ratings of perceived exertion were measured at exhaustion in the V_{peak} test, during the first shuttle of the final walking phase of each 15 min block in part A of the LIST, and at exhaustion in part B.

3.3.6 Gut fullness and gastric discomfort

Gut fullness (GF) and gastric discomfort (GD) were assessed using anchored 10-point semantic differential scales (van Nieuwenhoven *et al*., 2005; appendix A4.6). During the preliminary testing session, the use of the scales was explained to the participants by reading out a set of standardised instructions, which are shown in figure 3.6. Following the explanations, the participant was given the opportunity to ask any questions they had concerning the use of the scales. The low and high points of both scales were then anchored, as described for RPE (section 3.3.5.1). Gut fullness and GD were assessed immediately on completion of each 15 min block in part A and at exhaustion in part B of the LIST in all studies.

Definition: How full does your stomach feel?

Instructions: 'During your exercise session, we would occasionally like to know how full your stomach is feeling. Please use this scale to tell us how full your stomach feels while you are exercising. Remember, we just want to know how full (or bloated / puffed out) your stomach feels. If you stomach feels completely normal while you are exercising, you should point to number 1 ("not full at all"). If your stomach feels very, very full, more full then you have ever felt it before, you should point to a number 10 ("extremely full"). If the fullness in your stomach is somewhere in between "not full at all" (1) and "extremely full"(10), then point to a number between 1 and 10. Remember, there are no right or wrong answers. Use *any* of the numbers to tell how your stomach feels when you are exercising.'

Definition: How upset does your stomach feel?

Instructions: 'While you are exercising, we would also like to know how upset your stomach is feeling. Just like before, please use this scale to tell us how upset your stomach feels while you are exercising. Remember, here we just want to know how upset your stomach feels, for example if you feel sick, have any cramps, or any painful feelings in your stomach. As before, if your stomach feels completely normal while you are exercising, you should point to number 1 ("not upset at all"). If your stomach feels very, very upset, more upset then you have ever felt it before, you should point to a number 10 ("extremely upset"). If the upset in your stomach is somewhere in between "not upset at all" (1) and "extremely upset"(10), then point to a number between 1 and 10. Remember, there are no right or wrong answers. Use *any* of the numbers to tell how your stomach feels when you are exercising.'

Figure 3.6 Instructions for the use of the gut fullness and gastric discomfort semantic differential scales that were read to each participant during the preliminary visit in each study.

3.3.7 Body mass loss and sweat rate

Body mass loss (kg) for the duration of the protocol was calculated using the following equation (Edwards *et al*., 2007):

Pre-exercise BM (kg) – Post exercise BM (kg) + fluid ingested (L^{-1}) – urine output (L^{-1})

Sweat rate ($L.h^{-1}$) for the duration of the protocol was calculated using the equation (Edwards *et al*., 2007):

(Pre-exercise BM (kg) + fluid ingested (L^{-1}) – urine output (L^{-1}) – post-exercise BM (kg)) / protocol duration (min) x 60

Body-mass relative SR ($ml.kg^{-1}$ $BM.h^{-1}$) for the duration of the protocol was calculated using the following equation:

(Sweat rate ($L.h^{-1}$) / pre-exercise BM (kg)) * 1000

A worked example of all three equations is in table 3.2. The SR calculations do not account for BM loss due to fuel oxidation and respiratory fluid loss, but it is unlikely these would differ between trials (Edwards *et al.*, 2007).

Table 3.2 An example of calculating body mass loss (kg) and sweat rate ($L.h^{-1}$ and $ml.kg^{-1}$ $BM.h^{-1}$) for the duration of the Loughborough Intermittent Shuttle Test.

Body Mass Loss

Body mass loss (kg) = Pre-exercise BM (kg) – Post exercise BM (kg) + fluid ingested (L^{-1}) – urine output (L^{-1})

Pre-exercise BM: 66.6 kg
Post-exercise BM: 66.2 kg
Fluid ingested: 0.87 L^{-1}
Urine Output: 0.11 L^{-1}

Body mass loss (kg) = 66.6 – 66.2 + 0.87 – 0.11

Body mass loss = 1.2 kg

Sweat Rate

Sweat rate ($L.h^{-1}$) = (Pre-exercise BM (kg) + fluid ingested (L^{-1}) – urine output (L^{-1}) – post-exercise BM (kg)) / protocol duration (min) x 60

Pre-exercise BM: 66.6 kg
Post-exercise BM: 66.2 kg
Fluid ingested: 0.87 L^{-1}
Urine Output: 0.11 L^{-1}
Protocol duration: 74.3 min

Sweat rate ($L.h^{-1}$) = (66.6 + 0.87 – 0.11 – 66.2) / 74.3 x 60

Sweat rate = 0.94 $L.h^{-1}$

Sweat rate ($ml.kg^{-1}$ $BM.h^{-1}$) = (SR ($L.h^{-1}$) / pre-exercise BM (kg)) * 1000

Sweat Rate: 0.72 $L.h^{-1}$
Pre-exercise BM: 66.6 kg

Sweat rate ($ml.kg^{-1}$ $BM.h^{-1}$) = (0.72 / 66.6) * 1000

Sweat rate = 10.81 $ml.kg^{-1}$ $BM.h^{-1}$

3.3.8 Ambient temperature and relative humidity

Ambient temperature and relative humidity were recorded using a digital hygro-thermometer (Tako Astatic Technology, Malaysia). The hygro-thermometer had an indoor ambient temperature and relative humidity range of 0-50^{o}C and 20-99%,

respectively, and a stated accuracy of ± 1°C and ± 3%, respectively (Tako Astatic Technology, 2007). Measurements were taken at the beginning of the preliminary test, immediately before the start of the LIST, and at the end of each 15 min block of part A.

3.4 Statistical analysis

The Shapiro-Wilk test for normality was employed on all data sets. For all analysis of variance (ANOVA) analyses, the Greenhouse-Geisser adjustment of the degrees of freedom was applied if the Mauchly Test of Sphericity was compromised (Field, 2005). Effect sizes from ANOVA were calculated using partial eta squared (η^2) values, which were square rooted to give correlation coefficients (Field, 2005). Effect sizes from *t* scores were calculated using the equation of Rosnow and Rosenthal (2005), and from *z* scores using the equation of Rosenthal (1991), to give *r* scores (Field, 2005). This method was employed as the ES values are constrained to lie within a set range (0-1) and are therefore easy to interpret (Field, 2005). Furthermore, the method is widely understood and frequently used. Finally, the method is flexible and could be consistently applied across the different statistical tests employed in this thesis, thereby allowing within- and between-studies interpretation of ES (Field, 2005). Effect sizes were defined as small (r = 0.1-0.3), moderate (r = 0.3-0.5), large (r = 0.5-0.7), very large (r = 0.7-0.9), or nearly perfect (r = 0.9-1.0), based on the classifications of Hopkins (2006). Unless specified, data were mean ± standard deviation (SD), and statistical significance was set at $P < 0.05$. Specific information on the statistical tests employed in each study is detailed in the relevant chapters.

Chapter 4: The Influence of Ingesting a 6% Carbohydrate-Electrolyte Solution Immediately Before, and During, Prolonged Intermittent, High-Intensity Exercise on the Intermittent Endurance Capacity, Sprint Performance, and Physiological Response of Adolescent Team Games Players

Abstract

The aim of this study was to investigate the influence of consuming a 6% carbohydrate-electrolyte (CHO-E) solution on the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players. Fifteen participants (10 males and 5 females; mean age 12.7 ± 0.8 years, height 166.4 ± 8.7 cm, body mass (BM) 55.6 ± 10.4 kg) performed two trials separated by 3–7 days. In each trial, they completed 60 min of exercise composed of four 15-min periods of part A of the Loughborough Intermittent Shuttle Test (LIST), followed by an intermittent run to exhaustion (part B). Participants consumed either the 6% CHO-E solution or a non-carbohydrate (CHO) placebo (PLA; 5 $ml.kg^{-1}$ BM) during the 5 min pre-trial and after each 15-min period of part A (2 $ml.kg^{-1}$ BM). Intermittent endurance capacity was increased by 24.4% during part B when CHO was ingested (5.1 ± 1.8 vs. 4.1 ± 1.6 min, $P < 0.05$, $r = 0.51$), with distance covered in part B also significantly greater in the CHO trial (851 ± 365 vs. 694 ± 278 m, $P < 0.05$, $r = 0.52$). No significant between-trials differences were observed for mean 15 m sprint time ($P = 0.35$, $r = 0.27$), peak sprint time ($P = 0.77$, $r = 0.08$), or heart rate (HR; $P = 0.08$, $r = 0.48$) during part A. These results demonstrate that ingestion of a 6% CHO-E solution significantly improves the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

4.1 Introduction

Physiological studies of adult field-based team games (soccer, rugby and field hockey) suggest a mean whole-game exercise intensity of 70-80% $\dot{V}O_{2max}$, analogous

to prolonged moderate to high-intensity steady state exercise (Bangsbo *et al*., 2006). As with prolonged steady state exercise, significant glycogen depletion can occur during team games, which in soccer can reduce the amount of total and high-intensity work completed, distance covered, and the number of sprints achieved, particularly in the second half of a game (Balsom *et al*., 1999; Saltin, 1973). This evidence of muscle glycogen depletion and performance decrement suggests that ingestion of CHO solutions during team games may be beneficial.

Nicholas *et al*. (1995) conducted the first standardised, well-controlled laboratory study to investigate CHO supplementation during exercise designed to simulate the physiological demands of soccer. Using the LIST, ingestion of a 6.9% CHO-E solution enabled a 33% longer time to exhaustion during prolonged intermittent, high-intensity running compared with a PLA. No significant between-trials difference was found for exercise performance, measured as repeated 15 m sprint time. Subsequent research on CHO supplementation during the LIST supports this initial finding on exercise capacity in adults (Ali *et al*., 2007; Davis *et al*., 2000; Welsh *et al*., 2002), with only three studies finding a significant influence on sprint performance (Ali *et al*., 2007; Welsh *et al*., 2002; Winnick *et al*., 2005).

Young people typically exhibit an exercising metabolic profile consisting of greater fat and lower CHO oxidation than adults (Aucouturier *et al*., 2008), although this is maturation dependent (Timmons *et al*., 2007[a]). However, research now indicates that young people are able to oxidise CHO_{exo} during exercise in BM-relative amounts equal to, or greater than, that of adults (Riddell *et al*., 2000; Timmons *et al*., 2007[a]). This intriguing finding implies that adolescents are able to readily access exogenously delivered CHO. This ability has also been associated with sparing of muscle glycogen (Riddell *et al*., 2000) and enhancement of steady-state endurance cycling capacity (Riddell *et al*., 2001). Taken together, this data suggests that consuming CHO during prolonged intermittent, high-intensity exercise may be of benefit to this population. Given the high participation rates in youth team games in England and Scotland (Malina, 2005; SportScotland, 2008), the lack of research into prolonged intermittent, high-intensity exercise in young people, and the evidence of

high rates of CHO_{exo} oxidation during exercise in this population, study in this area is timely.

Research using intermittent, high-intensity exercise protocols indicates that young people display less fatigue (assessed by decrements in PPO and MPO) during a given bout of relative-intensity exercise than adults (Ratel *et al*., 2002; Zafeiridis *et al*., 2005). This suggests that any benefits of CHO supplementation during prolonged intermittent, high-intensity exercise in adolescents would most likely manifest in improved intermittent endurance capacity as opposed to exercise performance.

There is a dearth of information regarding the effects of CHO ingestion in adolescents during prolonged intermittent, high-intensity exercise, as well as a lack of guidelines for CHO ingestion during any form of exercise in this age group. As a result, it would be inappropriate to use a [CHO] notably lower or greater than the commonly used, and widely commercially available, 6% solution.

Research Question: Does ingestion of a carbohydrate-electrolyte solution immediately before and during prolonged intermittent, high-intensity exercise influence the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players?

Hypothesis 1: Ingesting a carbohydrate-electrolyte solution will significantly increase the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 2: Ingesting a carbohydrate-electrolyte solution will not significantly influence the repeated 15 m sprint performance of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 3: Ingesting a carbohydrate-electrolyte solution will not significantly influence the physiological response, as measured

by HR, SR and BM loss, of adolescent team games players during prolonged intermittent, high-intensity exercise.

4.2 Methods

In addition to the general methods chapter (chapter 3), this section describes the exact protocols used, and any procedures or measurements exclusive to this study.

4.2.1 Participants

Fifteen team games players (10 males and 5 females) participated in the study. Physical and biological characteristics are in table 4.1.

Table 4.1 Physical and biological characteristics of participants. Data are mean ± SD (range).

	Age (years)	**Height (cm)**	**Body Mass (kg)**	**Maturity Offset (years)**
All participants (*n* = 15)	12.7 ± 0.8 (12-14)	166.4 ± 8.7 (150.5-184.1)	55.6 ± 10.4 (37.8-77.4)	+0.51 (-1.51-+1.89)

4.2.2 Preliminary tests

4.2.2.1 Peak running velocity

During their first visit to the laboratory, participants performed a familiarisation and V_{peak} test on a motorised treadmill (section 3.3.2) followed by a familiarisation of the LIST protocol, as described in section 3.2.1.

4.2.3 Experimental design

Participants' completed two experimental trials. During the trials they consumed either a 6% CHO-E solution (CHO trial) or a non-CHO PLA (PLA trial). Solution compositions were as follows:

Carbohydrate trial

The solution was 1 L^{-1} of water mixed with 60 g of CHO powder (100% maltodextrin; High5 Ltd, Bardon, UK) and two dissolvable electrolyte tablets (High5 Ltd, Bardon, UK). Total electrolyte composition of the solution was: Na^{+}, 250 mg; magnesium, 60 mg; K^{+}, 90 mg; calcium, 20 mg.

Placebo trial

The solution was 1 L^{-1} of water mixed with two dissolvable electrolyte tablets (High5 Ltd, Bardon, UK). Total electrolyte composition of the solution was: Na^{+}, 250 mg; magnesium, 60 mg; K^{+}, 90 mg; calcium, 20 mg.

The electrolyte tablets contained artificial sweetener (Saccharine and Acesulfame K) and were flavoured as citrus, berry, or cherry-orange. Prior to the first trial, each participant was asked which flavour they would prefer. The participants' chosen flavour was then used for both of their trials. Therefore, within-participants, all solutions were matched for colour, taste, texture, and feeling within the mouth. Pilot work confirmed that the artificially sweetened electrolyte tablets were an effective blinding agent.

4.2.4 Experimental protocol

Participants arrived at the laboratory in a fed, post-prandial state. For logistical reasons, it was not possible to test all participants at the same time of day, but within-participants sessions were completed at the same time of day or as near as possible.

Sessions began between 10am and 6pm. During each trial, participants performed the LIST protocol as detailed in section 3.2.2 and figure 3.4. A pre-exercise solution bolus of 5 $ml.kg^{-1}$ BM was ingested as described in section 3.2.2, followed by boluses of 2 $ml.kg^{-1}$ BM at each time point during exercise, in line with Nicholas *et al*. (1995; figure 3.4). In both trials, following the measurement of dry nude BM at the end of the protocol participants were asked to state which solution they believed they had consumed.

4.2.5 Measurements

All measurements made during the study are detailed in section 3.3.

4.2.6 Statistical analysis

The following details specific analyses for this study, in addition to that detailed in section 3.4. Paired *t*-tests compared between-trials differences in fluid intake, pre-exercise BM, BM loss and SR, distance covered during part A, and peak HR at exhaustion. Time to exhaustion, distance covered in part B, RPE, GF and GD at exhaustion in part B were analysed using the Wilcoxon matched-pairs test. Mean ambient temperature and relative humidity, mean sprint times, mean peak sprint times, HR and GF during part A were analysed with a 2 way (solution x time) ANOVA, using paired *t*-tests with Bonferroni correction to explore significant main effects. Wilcoxon matched-pairs tests with Bonferroni correction analysed between-trials differences for RPE and GD during part A, with Friedman tests assessing the main effect of time within each trial. Wilcoxon matched-pairs tests with Bonferroni correction explored significant within-trials main effects for these two measurements. Chi-square analysis assessed the frequency distribution of solution choice responses. Unless specified, data are mean ± SD.

4.3 Results

Insufficient females were recruited to perform between-gender statistical analyses, therefore the data was treated as a single cohort. The data was analysed with and without the female participants data included, and it was confirmed that significance was not affected by inclusion of the female data.

4.3.1 Preliminary tests

Mean V_{peak} attained in the incremental treadmill run to exhaustion was 14.6 ± 1.2 $km.h^{-1}$. Mean HR_{max} and RPE at exhaustion were 201 ± 8 beats per min and 9.0 ± 0.4, respectively.

4.3.2 Distance covered and time to exhaustion

By design, distance covered during part A was similar between the CHO and PLA trials at 7.1 ± 0.3 and 7.2 ± 0.3 km, respectively (P = 0.27, r = 0.21). Two participants failed to complete part B, one due to GI distress in the CHO trial and one to temporary respiratory distress in the PLA trial, and were excluded from all part B analyses, making n = 13 for part B data. Time to exhaustion during part B of the LIST for both trials is shown in figure 4.1, with time to exhaustion for each individual participant shown in figure 4.2. Participants ran for a significantly longer time in the CHO compared to the PLA trial (P < 0.05, r = 0.51), representing a 24.4% mean improvement in intermittent endurance capacity. Distance covered in part B was significantly greater in the CHO trial (851 ± 365 vs. 694 ± 278 m, P < 0.05, r = 0.52).

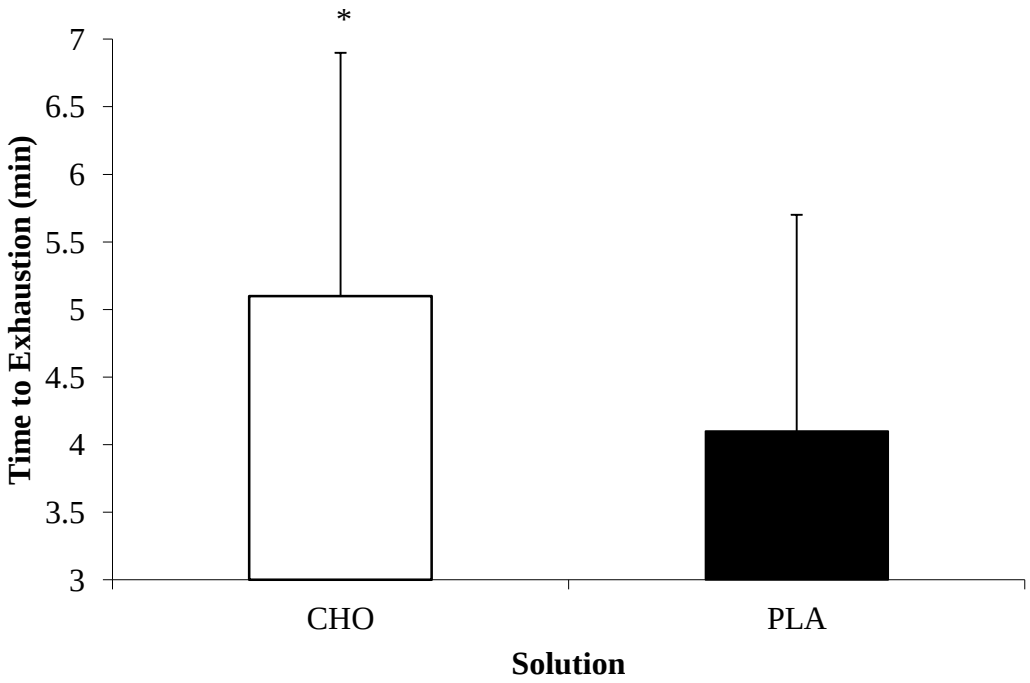

Figure 4.1 Time to exhaustion (min) during part B of the Loughborough Intermittent Shuttle Test for both trials. * significantly greater than the PLA trial, $P < 0.05$. Data are mean ± SD ($n = 13$).

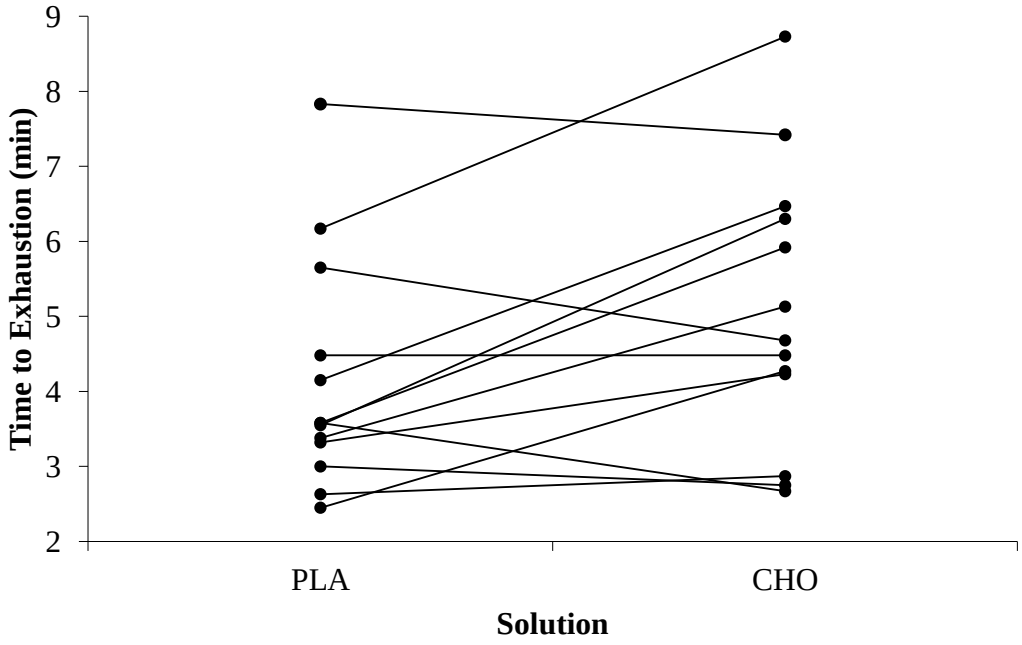

Figure 4.2 Time to exhaustion (min) during part B of the Loughborough Intermittent Shuttle Test for each participant in both trials ($n = 13$).

4.3.3 Sprint times

The mean time of all sprints, and the mean of participants' peak sprint time only, completed in each block of part A of the LIST are shown in figure 4.3A and 4.3B, respectively. There was a trend for faster sprint times throughout the LIST in the CHO trial, but this was not statistically significant ($F_{1, 12} = 0.96$, $P = 0.35$, $r = 0.27$). There was also no interaction effect (solution x time, $F_{3, 36} = 0.1$, $P = 0.96$, $r = 0.09$). There was a main effect of time on sprint duration ($F_{1.3, 15.6} = 29.1$, $P < 0.001$, $r = 0.84$). Sprint times in each block were significantly slower than the previous block ($P < 0.001$, $r = 0.69$ and 0.63 for blocks 2 and 3, respectively; $P < 0.005$, $r = 0.50$ for block 4). Mean peak sprint time was not significantly different between-trials ($F_{1, 13} = 0.09$, $P = 0.77$, $r = 0.08$), and there was no interaction effect ($F_{3, 39} = 1.13$, $P = 0.35$, $r = 0.28$). However, there was a trend for peak sprint times to be maintained slightly better in the PLA trial, with a mean decay between bouts 1 to 4 of 0.08 ± 0.03 s compared with 0.13 ± 0.03 s in the CHO trial. There was a main effect of time on peak sprint duration ($F_{2.1, 27.3} = 14.8$, $P < 0.001$, $r = 0.73$). Sprint times in block 2 were significantly slower then block 1 ($P < 0.005$, $r = 0.45$), and in block 3 were significantly slower than block 2 ($P < 0.001$, $r = 0.47$). There was no significant difference between blocks 3 and 4 ($P = 0.44$, $r = 0.14$).

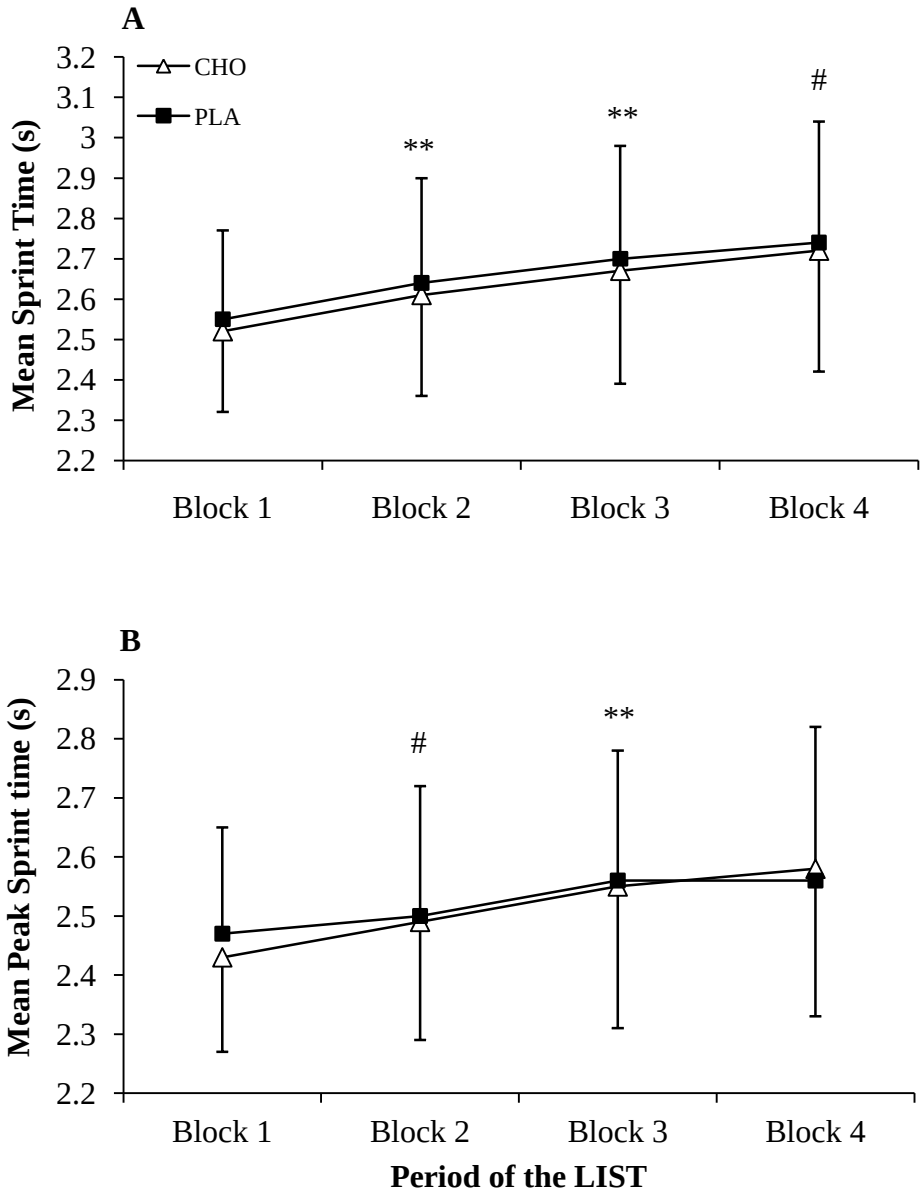

Figure 4.3 Mean sprint time (s, A) and mean peak sprint time (s, B) during part A of the Loughborough Intermittent Shuttle Test for both trials. Data are mean ± SD (n = 14). ** significantly greater than previous block, $P < 0.001$; # significantly greater than previous block, $P < 0.005$.

4.3.4 Heart rate, ratings of perceived exertion and gastric disturbances

Mean HR and RPE during part A of the LIST, and mean peak HR and mean RPE at exhaustion in part B, are shown in table 4.2. Heart rate throughout part A of the

LIST showed a trend for greater values in the CHO trial, but did not reach statistical significance ($F_{1, 12}$ = 3.67, P = 0.08, r = 0.48), and there was no interaction effect ($F_{1.8, 21.2}$ = 0.91, P = 0.41, r = 0.26). There was a main effect of time for HR in part A ($F_{1.2, 14.8}$ = 10.4, P < 0.005, r = 0.68). Heart rate in block 2 was significantly greater than block 1 (P < 0.001, r = 0.78). There was no significant difference between blocks 2 and 3 (P = 0.74, r = 0.07) or 3 and 4 (P = 0.12, r = 0.30). Peak HR at exhaustion in part B was significantly greater in the CHO trial (P < 0.05, r = 0.55). Ratings of perceived exertion were very similar at all time points between trials, with no significant differences found. A main effect of time was present for the CHO ($\chi^2(3)$ = 32.5, P < 0.001) and PLA ($\chi^2(3)$ = 40.8, P < 0.001) trials. Ratings of perceived exertion increased significantly with each successive exercise block (P < 0.001, r = 0.78, 0.76 and 0.72, respectively). There was no significant between-trials difference in RPE at exhaustion (P = 0.71, r = 0.10).

Table 4.2 Mean heart rate (percentage of maximum heart rate) and mean ratings of perceived exertion during part A of the Loughborough Intermittent Shuttle Test, and mean peak heart rate and mean ratings of perceived exertion at exhaustion in part B for both trials. Data are mean ± SD (n = 14 for heart rate in part A, n = 13 for peak heart rate in part B, n = 15 and 13 for ratings of perceived exertion in part A and B, respectively).

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean heart rate (percentage of maximum)					
CHO	82.6 ± 3.5	84.6 ± 3.0**	84.8 ± 3.5	84.1 ± 3.7	95.6 ± 2.5*
PLA	81.1 ± 4.7	82.7 ± 5.1**	82.5 ± 4.5	82.5 ± 3.6	94 ± 3.0
Mean ratings of perceived exertion					
CHO	5.7 ± 1.7	6.7 ± 1.1**	7.5 ± 0.7**	8.3 ± 0.6**	9.2 ± 0.7
PLA	5.5 ± 1.3	6.8 ± 1.0**	7.6 ± 0.9**	8.5 ± 0.7**	9.2 ± 0.4

CHO = carbohydrate trial; PLA = placebo trial

** significantly greater than previous block, $P < 0.001$; * significantly greater than the PLA trial, $P < 0.05$

Mean GF and GD during part A of the LIST, and at exhaustion in part B, are shown in table 4.3. Mean GF remained quite stable throughout the protocol in both trials, with no solution ($F_{1, 14} = 0.17$, $P = 0.69$, $r = 0.11$), time ($F_{3, 42} = 1.44$, $P = 0.25$ $r = 0.30$), or interaction effects ($F_{1.8, 25.4} = 0.38$, $P = 0.67$, $r = 0.16$). Gut fullness scores during part A of the LIST were modest. There was a trend for GF at exhaustion to be higher in the CHO trial, but this was not significant ($P = 0.24$, $r = 0.14$). Gastric discomfort increased significantly with time in the CHO ($\chi^2(3) = 15.8$, $P < 0.005$) and PLA ($\chi^2(3) = 8.3$, $P < 0.05$) trials, and showed a non-significant trend for greater values in the CHO trial. In the CHO trial, GD in block 2 was significantly greater than block 1 ($P < 0.01$, $r = 0.76$), with no significant difference between blocks 2 and 3 ($P = 0.45$, $r = 0.16$) or 3 and 4 ($P = 0.19$, $r = 0.23$). In the PLA trial, the location of

differences could not be determined. Despite the significant main effect of time, GD scores during part A of the LIST were modest. There was a trend for GD at exhaustion to be greater in the CHO trial, but this was not significant (P = 0.67, r = 0.14).

Table 4.3 Mean gut fullness and gastric discomfort ratings during part A of the Loughborough Intermittent Shuttle Test, and at exhaustion in part B, for both trials. Data are mean ± SD (n = 15 and 13 for part A and B, respectively).

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean gut fullness ratings					
CHO	3.6 ± 1.5	4.1 ± 2.0	4.2 ± 1.9	3.8 ± 1.6	5.0 ± 1.8
PLA	3.5 ± 1.9	3.6 ± 1.6	3.9 ± 1.7	3.9 ± 1.7	4.2 ± 2.1
Mean gastric discomfort ratings					
CHO	2.9 ± 2.0	3.8 ± 2.2†	4.0 ± 2.3	4.4 ± 2.5	4.5 ± 2.7
PLA	2.8 ± 1.6	3.0 ± 1.9	3.5 ± 2.4	3.8 ± 2.8	4.2 ± 2.8

CHO = carbohydrate trial; PLA = placebo trial

† significantly greater than previous block in the same trial, $P < 0.01$

4.3.5 Body mass loss and sweat rate

Mean pre-exercise dry nude BM was not significantly different between the CHO and PLA trials (56.8 ± 9.4 and 56.9 ± 9.6 kg, respectively, P = 0.30, r = 0.16). Mean BM loss in the CHO and PLA trials was 0.9 ± 0.2 and 0.9 ± 0.2 kg, respectively (P = 0.33, r = 0.20), equating to a mean loss of 1.54 ± 0.32 and 1.62 ± 0.37% of pre-exercise BM (P = 0.23, r = 0.23). Mean SR was 0.71 ± 0.19 and 0.72 ± 0.18 $L.h^{-1}$ in the CHO and PLA trials, respectively (P = 0.70, r = 0.06), equating to a BM-relative mean sweat loss of 12.43 ± 2.00 and 12.77 ± 2.76 $ml.kg^{-1}$ $BM.h^{-1}$, respectively (P = 0.51, r = 0.13).

4.3.6 Blinding, fluid and carbohydrate intake

Of the 15 participants, seven (47%) correctly identified both solutions post-exercise and eight (53%) failed to do so. Chi square analysis of the responses in the CHO trial found a non-significant deviation from the expected response frequency ($\chi^2(1) = 0.067$, $P = 0.80$). Mean fluid intake was 739 ± 122 and 740 ± 125 ml for the CHO and PLA trials, respectively ($P = 0.33$, $r = 0.13$). In the CHO trial, this equated to a mean CHO intake of 34.7 ± 5.7 $g.h^{-1}$, or 0.78 $g.kg^{-1}$ BM.

4.3.7 Ambient temperature and relative humidity

Mean ambient temperature and relative humidity immediately before and during the LIST are shown in table 4.4. Mean ambient temperature was not significantly different between trials ($F_{1, 13} = 0.55$, $P = 0.47$, $r = 0.20$), but there was a main effect of time ($F_{1.1, 14.1} = 19.41$, $P < 0.001$, $r = 0.77$). Mean ambient temperature was significantly different between pre-exercise and block 1 ($P < 0.05$, $r = 0.61$), block 1 and 2 ($P < 0.05$, $r = 0.61$), and block 3 and 4 ($P < 0.05$, $r = 0.38$). There was no significant difference between block 2 and 3 ($P = 0.06$, $r = 0.41$). There was no interaction effect for mean ambient temperature ($F_{1.2, 15.9} = 1.83$, $P = 0.20$, $r = 0.35$). Mean relative humidity was not significantly different between ($F_{1, 13} = 0.09$, $P = 0.77$, $r = 0.08$) or within ($F_{1.7, 22.1} = 5.79$, $P = 0.15$, $r = 0.38$) trials, and there was no interaction effect ($F_{1.9, 24.1} = 0.10$, $P = 0.89$, $r = 0.09$).

Table 4.4 Mean ambient temperature (^{o}C) and relative humidity (%) immediately before, and during, part A of the Loughborough Intermittent Shuttle Test for both trials. Data are mean ± SD (n = 14).

	Period of the LIST				
	Pre-exercise	Block 1	Block 2	Block 3	Block 4
Mean ambient temperature (^{o}C)					
CHO	19.4 ± 1.2	19.6 ± 1.2^	19.7 ± 1.2^	19.8 ± 1.2	19.8 ± 1.3^
PLA	19.7 ± 1.3	19.9 ± 1.3^	20.0 ± 1.3^	20.0 ± 1.3	20.1 ± 1.4^
Mean relative humidity (%)					
CHO	51.2 ± 15.4	50.8 ± 15.2	50.6 ± 15.1	50.4 ± 14.9	50.5 ± 14.9
PLA	50.4 ± 12.9	50.1 ± 12.9	50.1 ± 12.6	49.8 ± 12.5	49.7 ± 12.7

CHO = carbohydrate trial; PLA = placebo trial

^ significantly greater than previous block, $P < 0.05$

4.4 Discussion

This study found that ingestion of a 6% CHO-E solution immediately before, and during, prolonged intermittent, high-intensity exercise significantly improves the intermittent endurance capacity of adolescent team games players. Carbohydrate supplementation had no significant influence on sprint performance, but did exert a possible influence on HR response at the end of the exercise protocol.

4.4.1 Time to exhaustion

The 24.4% improvement in time to exhaustion with CHO supplementation in the current study is a significant finding, which is further reinforced by the large ES (r = 0.51). However, it is lower than the range of improvement found in adult studies using the standard LIST (32-52%; Davis *et al*., 2000; Davis *et al*., 1999; Nicholas *et al*., 1995, section 2.3.5). This adult research has proposed two mechanisms, whereby

CHO_{exo} supplementation may either spare muscle glycogen use or increase its resynthesis during exercise, for enhanced intermittent endurance capacity with CHO ingestion (Davis *et al*., 2000; Nicholas *et al*., 1995; Nicholas *et al*., 1999). This greater muscle glycogen concentration may then enable greater intermittent endurance capacity late in exercise, as it is unlikely that blood glucose oxidation (via CHO supplementation) could significantly extend time to fatigue without adequate muscle glycogen stores (Coggan and Coyle 1988; Nicholas *et al*., 1995). However, it should be noted that this mechanism is not universally supported, at least during prolonged steady-state exercise (Coyle *et al*., 1986).

The current study was descriptive, and therefore not designed to identify specific mechanisms of enhancement. However, there are reasons to suggest that glycogen sparing may also occur in adolescents when CHO is consumed during prolonged intermittent, high-intensity exercise. Endogenous muscle and hepatic glycogen concentrations are lower in early adolescence compared to adulthood (Aucouturier *et al.,* 2008). Furthermore, young people exhibit a greater rate of fat oxidation at a given relative exercise intensity than adults (Aucouturier *et al*., 2008). This is suggested to be a glycogen-conserving response rather than a metabolic inability to oxidise more CHO, due to the observation that young people are able to readily oxidise CHO_{exo} during exercise (Riddell, 2008, Timmons *et al*., 2003). These metabolic distinctions between young people and adults provide hypotheses for the efficacy of CHO supplementation in adolescents, and the possible mechanisms behind this efficacy.

It is possible that the greater fat oxidation of young people compared with adults during exercise (Timmons *et al*., 2003) might in some way reduce the impact of ingested CHO and contribute to the smaller percentage improvement in this compared with adult studies. Timmons *et al*. (2007[a]) found similar fat oxidation rates during exercise between PP, EP, and MP/LP boys, with a reduction in CHO_{exo} oxidation in MP/LP boys. The participants in this study were classified as average maturers, with a mean maturity offset of +0.51 years, suggesting that, as a group, puberty in these participants was underway (Karlberg, 2002). This provides some

support for the fat oxidation hypothesis discussed above. However, the absence of metabolic measures, coupled with the reported variance of the maturity offset equations (section 3.2.3), means the specific metabolic response of the participants in this study cannot be conclusively determined. However, four blocks of part A of the LIST were conducted in this study, compared with at least five in adult work (Nicholas *et al*., 1995; Davis *et al*., 2000; Davis *et al*., 1999). While this was appropriate due to the shorter duration of youth team sports (Ekblom, 1986), and helps to explain the shorter part A distance compared with adult work (Nicholas *et al*., 1995), it may have led to a lesser depletion of glycogen stores in both trials. This could also have contributed to the smaller effect of CHO. However, this cannot be confirmed without assessing resting muscle glycogen concentration. Additionally, the potentially lower endogenous glycogen concentration of young participants may negate the glycogen sparing effect of a shorter exercise protocol. Finally, mean BM-relative CHO intake in this study was notably lower than adult work (section 4.4.4). This lower CHO intake may have contributed to the lower improvement in intermittent endurance capacity in this study compared with adult work. The efficacy and relative influence of these hypotheses cannot be determined at this time.

It should also be considered that participants in this study were in a fed, post-prandial state when exercising. Pre-exercise nutritional status can influence substrate use during exercise, exercise performance, and the effect of CHO ingested during exercise (Chryssanthopoulos & Williams, 1997; Coyle *et al*., 1985; Neufer *et al*., 1987). Consuming a pre-exercise CHO meal along with ingestion of CHO during exercise can improve exercise performance more than CHO ingestion during exercise alone (Chen *et al*., 2009; Chryssanthopoulos & Williams, 1997). However, other authors have not found this to be the case (Burke *et al*., 1998; Wong *et al*., 2009). Therefore, it is possible that the lack of pre-exercise fasting, and the potential inter-individual variation in pre-exercise nutritional status in the current study may have contributed to the lower intermittent endurance capacity compared with adult work.

In the current study, time to exhaustion in the CHO and PLA trials was somewhat shorter than most adult research, which ranges from 8.9-11.2 min in the CHO trial and 6.4-8.5 min in the PLA trial (Davis *et al*., 1999; Davis *et al*., 2000; Nicholas *et al*., 1995). Although research is scarce, it appears that when exercise is carried out at the same relative intensity there is no difference in endurance capacity between boys and young men (Rowland *et al*., 2008). As exercise intensity in this and adult research was individually standardised, it could have been expected that intermittent endurance capacity in the current study would have been nearer to that cited in previous adult work. However, running speeds in the current study were calculated based on percentages of V_{peak}, as opposed to percentages of $\dot{V}O_{2max}$ in adult research. While $\dot{V}O_2$ and running speed do increase linearly, this relationship is unlikely to be perfectly linear throughout a progressive exercise test, particularly at high intensities, where a slow component of $\dot{V}O_2$ is observed (Poole *et al*., 1994). Therefore, calculating speeds associated with 55 and 95% of $\dot{V}O_{2max}$ may elicit different speeds, and hence intensities, than the calculation of 55 and 95% of V_{peak}. This is more likely when considering that previous adult research estimated $\dot{V}O_{2max}$ using a progressive shuttle run test (Davis *et al*., 2000; Nicholas *et al*., 1995), with Nicholas *et al*. (1995) calculating running velocities from normative data tables based on this test. This means the use of regression analysis to calculate accurately the speeds associated with 55 and 95% of $\dot{V}O_{2max}$ for each participant was not possible. It may be that the intensities used in the current study were relatively greater than those prescribed in previous adult research, which may have contributed to the shorter times to exhaustion. It should also be stated that the times to exhaustion in this study were greater than those reported by Welsh *et al*. (2002) of 3.58 and 2.61 min for the CHO and PLA trials, respectively. However, the structure of the LIST in that study was different (table 2.9).

4.4.2 Sprint performance

The lack of influence of CHO supplementation on sprint performance in this study is in line with most previous adult work (Davis *et al* 2000; Nicholas *et al* 1995; Nicholas *et al* 1999, section 2.3.3). Initially, it appears unsurprising that CHO intake

had no influence on sprint performance, as when glycogen depletion is not severe it is PCr availability and its rate of resynthesis, rather than CHO availability, that determines short-duration sprint performance (Greenhaff *et al*., 1994), and PCr resynthesis rates may be faster in young people than adults (Taylor *et al*., 1997, section 2.1.5.2.1). However, as discussed in section 2.3.7.2, during prolonged intermittent, high-intensity exercise full PCr resynthesis may not be achieved due to activities undertaken between sprints that increase competition for O_2 between PCr resynthesis and processes including La oxidation, oxymyoglobin replenishment, and the O_2 demand of the activities. Supporting this, reduced PPO during repeated sprints with active versus passive recovery has been demonstrated in young participants (mean age 15.9 years; Thevenet *et al*., 2007). Incomplete PCr resynthesis may explain why sprint times progressively slowed throughout the LIST, in line with some previous adult work (Ali *et al*., 2007; Foskett *et al*., 2008; Morris *et al*., 2003). In the current study, the between-trials physiological demand was standardised. Additionally, CHO ingestion does not exert an influence on PCr kinetics. Therefore, PCr kinetics were expected to be similar between trials. Also, undertaking the protocol in a fed, post-prandial state may have ensured that muscle glycogen in both the CHO and PLA trials did not drop below levels that can attenuate sprint performance (Bangsbo *et al*., 2006). This may have negated any potential benefit of CHO ingestion on sprint performance during the LIST, and could explain the similar between-trials sprint response. However, if PCr resynthesis was unable to contribute fully to each sprint as the protocol continued, CHO and fat would become more prevalent fuels for sprinting (Spencer *et al*., 2006), suggesting CHO supplementation may be important for maintaining sprint performance during the later stages of team games exercise. This is supported by some evidence of a significantly faster, or significantly better maintained, sprint performance in the latter stages of prolonged intermittent, high-intensity exercise when a CHO-E solution is ingested compared with a PLA (Welsh *et al*., 2002; Winnick *et al*., 2005). There is currently no evidence supporting this in young people.

In the current study, the mean increase in sprint time from the first to the last block in part A of 0.20 and 0.19 s in the CHO and PLA trials, respectively, is notably greater

than that recorded in some previous adult work (0.08 s for both trials; Ali *et al*., 2007; Morris *et al*., 2003). It appears the young participants in this study did not display a greater fatigue resistance than adults when sprinting during the LIST, as may have been expected (section 2.1.6.2), and in fact showed an inferior ability to maintain sprint performance, supported by the large ES for the differences in sprint time between each exercise block. This may be due to the slightly different exercise intensities employed in the current study compared with adult research, as discussed in section 4.4.1. This interesting finding warrants further investigation.

This is the first study to investigate peak sprint time throughout the LIST. A similar response was observed to that of the mean of all sprints in each block, namely no significant between-trials difference and a progressive increase in peak sprint duration over time. Peak sprint time seemed to be maintained slightly better in the PLA trial, although this may have been due to peak sprint time in block 1 being a non-significant 0.03 s slower in the PLA trial than the CHO trial. Indeed, peak sprint time in the PLA trial displayed a trend for being slower than the CHO trial in all blocks except block 4. These findings lend further support to the view that CHO ingestion during prolonged intermittent, high-intensity exercise does not have a significant impact on repeated short duration sprint performance in young people.

4.4.3 Heart rate and ratings of perceived exertion

The similar between-trials HR and RPE responses during part A of the LIST in the current study are in agreement with most previous adult research (Ali *et al*., 2007; Foskett *et al*., 2008; Morris *et al*., 2003; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Welsh *et al*., 2002, section 2.3.5). This suggests that participants encountered a similar physiological load during both trials. Mean HR during part A of the LIST in the CHO trial was in agreement with values reported during outdoor 11-a-side and indoor 5-a-side soccer matches in recreational and elite young players (Castagna *et al*., 2007; Castagna *et al*., 2009; Castagna *et al*., 2010, section 2.2.2.3.1).

It would be inappropriate to compare HR values in this study with those of adult research (section 2.1.2). Furthermore, in order to normalise the data in the current study, HR values were expressed relative to individual HR_{max} achieved during the preliminary tests, whereas in adult research HR was reported in beats per min. However, the significant influence of time on HR in this study is again in line with previous adult work (Ali *et al*., 2007; Foskett *et al*., 2008; Morris *et al*., 2003). Additionally, the trend for HR to increase most notably from block 1 to 2, before levelling off or even declining in subsequent blocks, closely replicates some adult findings (Davis *et al*., 1999). Furthermore, the non-significant trend for a higher HR in the CHO trial has been observed in adult participants beginning the LIST in glycogen depleted and supplemented states (Ali *et al*., 2007; Foskett *et al*., 2008). Ali *et al*. (2007) demonstrated a significant improvement in sprint performance with CHO supplementation, which could explain the higher HR in the CHO trial in that study. In the current study, mean sprint time throughout part A of the LIST showed a trend for being faster in the CHO trial, and elicited a moderate ES. This may explain the non-significantly higher HR in the CHO trial.

The progressive increase in RPE with time during part A of the LIST agrees with adult research (Ali *et al*., 2007; Backhouse *et al*., 2007; Morris *et al*., 2003; Foskett *et al*., 2008; Nicholas *et al*., 1995; Nicholas *et al*., 1999). The apparent dissociation between HR and RPE during part A of the LIST in adolescents indicates that cues for the development of RPE are arising from a currently unidentified source(s), perhaps related to cumulative fatigue as a result of incomplete recovery from the previous exercise bouts. However, this needs to be quantified in adolescent participants. The non-significant between-trials difference in RPE during part A of the LIST agrees with relevant adult research (Ali *et al.*, 2007; Backhouse *et al.*, 2007; Morris *et al.*, 2003; Foskett *et al.*, 2008; Nicholas *et al.*, 1995; Nicholas *et al.*, 1999; Patterson and Gray, 2007).

The significantly greater peak HR at exhaustion in the CHO trial in this study has not been observed in previous work. Nicholas *et al.* (1995) recorded a non-significant 1.1% greater peak HR at exhaustion in the CHO trial, compared to the 1.6%

difference in this study. It is possible that the ergogenic effect of the CHO enabled participants to continue working to a higher intensity via better maintenance of muscle metabolism, whereas in the PLA trial less glycogen availability could have resulted in the inability of participants to maintain the required work output, and therefore reach exhaustion, at a lower relative intensity. This would still represent a maximal effort for both trials and support the mechanisms of action with CHO ingestion discussed in section 4.4.1; however, metabolic measurements are needed to confirm this hypothesis.

Alternatively, greater part B performance in the CHO trial may relate to the influence of CHO on perceptual responses to exercise. It has recently been demonstrated that CHO ingestion can significantly attenuate RPE during a standardised 2 h intermittent cycling protocol (Utter *et al*., 2007), and Backhouse *et al*. (2007) suggest this could also occur during the LIST. It appears that CHO supplementation may facilitate a more favourable perception of the demands of the exercise bout, resulting in participants recording a lower RPE score at a given exercise intensity (Backhouse *et al*., 2007; Utter *et al*., 2007), or achieving a higher intensity for a given RPE. Further support for this comes from Rollo *et al*. (2008), who demonstrated a significantly faster running speed at a given RPE when participants were provided with a CHO mouthwash. This demonstrates a role for CHO in improving exercise performance unrelated to its commonly cited metabolic influences, possibly related to activation of brain regions associated with reward and motor control mediated by the detection of CHO in the oral cavity (Chambers *et al*., 2009; Rollo *et al*., 2008). This is partly supported in the current study by the observation that RPE at exhaustion in part B was the same between-trials, despite the significantly higher HR in the CHO trial.

4.4.4 Fluid and carbohydrate intake

Mean fluid intake during the LIST in this study was notably lower than that of previous related research, for two reasons. Firstly, all previous research used adult participants with a much greater mean BM than the participants in this study (Ali *et al*. 2007; Morris *et al*., 2003; Nicholas *et al*., 1995; Nicholas *et al*., 1999). As fluid

intake in this and the other research was standardised to individual BM, less fluid was ingested in the current study. Secondly, previous research conducted at least five blocks of part A of the LIST, compared with four in the present study (Ali *et al*., 2007; Backhouse *et al*., 2007; Davis *et al*., 2000; Foskett *et al*., 2008; Morris *et al*., 2003; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Welsh *et al*., 2002). This means there was at least one less drink period in the current study. These reasons also explain the lower CHO intake in this study compared to previous adult investigations (41-47 $g.h^{-1}$, or 0.96-1.03 $g.kg^{-1}$ BM, or ~0.70-0.85 $g.min^{-1}$; Ali *et al*., 2007; Morris *et al*., 2003; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Welsh *et al*., 2002). As this is the first study of its kind, and due to the lack of information or guidelines regarding CHO ingestion in adolescents during prolonged intermittent, high-intensity exercise, it was decided to keep the [CHO] and ingestion volumes in line with previous research in order to generate data comparable to existing findings. Based on the findings of this study, the impact of variations in CHO intake during the LIST in adolescents requires investigation.

4.4.5 Gut fullness and gastric discomfort

None of the previous research investigating CHO solution ingestion during the LIST measured GF or GD. Research has demonstrated a negative relationship between ingested [CHO] of 2.5 – 17% and the rate of GE (Maughan & Leiper, 1994). Conversely, the rate of GE of an ~6% CHO solution may not be significantly slowed during the LIST or similar exercise (Leiper *et al*., 2005). The GF response, coupled with the SR and BM loss data (section 4.4.6), in this study suggests that regular ingestion of a 6% CHO-E solution does not slow GE to the extent where fluid availability, and hence thermoregulation, become notably impaired. The intermittent endurance capacity data also indicates that sufficient CHO was absorbed from the intestine into the systemic circulation to enhance intermittent endurance capacity. This leaves the question of what caused the main effect of time for GD in both trials. As it appears to be a CHO independent cause, it may be speculated that the young participants, when asked the question ‘how upset does your stomach feel?’ found it difficult to distinguish between GD and discomfort of other localised origins.

Exercise-related transient abdominal pain, commonly known as a stitch, is a common complaint during exercise, particularly running (Morton & Callister, 2000). Suggested hypotheses include diaphragmatic ischemia, visceral ligament stress, irritation of the parietal peritoneum, and musculoskeletal pain/cramp (Eichner, 2006; Morton & Callister, 2000). Furthermore, gut ischemia, perhaps caused by a redirection of blood flow from the gut to the working muscles during intense exercise, can cause GD (de Oliveira & Burini, 2009), and the prevalence of this is almost twice as high in running than other endurance sports (de Oliveira & Burini, 2009). All of these factors are independent of CHO ingestion, and occurrence of any during exercise in the current study would likely have contributed to a higher GD rating. A small number of participants did report experiencing symptoms of a stitch during exercise, which may help to explain the increase in GD independent of treatment and GF measures. This is an issue that must be considered when attempting to collect gastric sensation data during studies of this nature, particularly when using adolescent participants. From this data, it appears that adolescent team games players are generally able to tolerate well a 6% CHO-E solution during prolonged intermittent, high-intensity exercise.

4.4.6 Body mass loss and sweat rate

Mean pre-exercise dry nude BM was not significantly different between-trials, indicating a similar pre-exercise hydration status. This is further confirmed by no significant between-trials difference in BM loss and SR, inferring similar thermoregulatory function. This also suggests that participants experienced comparable thermal stress during each trial, supported by the similar between-trials ambient temperature and humidity (section 4.3.7).

The non-significant between-trials difference in BM loss in this study is in line with previous adult work (Ali *et al*., 2007; Nicholas *et al*., 1995; Nicholas *et al*., 1999). These figures are notably lower than values ranging from 3.0 – 3.7% reported by Nicholas *et al*. (1995) and Nicholas *et al*. (1999), but in line with other findings of 0.7– 1.8% (Ali *et al*., 2007; Morris *et al*., 2003). It should be remembered that the

protocol in the current study is shorter than that of previous research, perhaps by as much as 15-20 min, which would affect the SR data. Furthermore, young people have a lower absolute and relative SR than adults (Rowland, 2008). Therefore, the most likely explanations for differences in BM loss and SR between this study and adult research using the LIST is the shorter duration of the protocol in the current study, and the lower SR of young people compared to adults. No other BM loss and SR data in adolescents during prolonged intermittent, high-intensity exercise is currently available, therefore comparison of values with other related work is not possible at this time.

4.4.7 Blinding

In a study using two perfectly blinded solutions, it could be expected that 50% of participants would correctly identify both solutions by chance alone (Boutron *et al*., 2005). Therefore, the blinding procedures in this study appeared successful (section 4.3.6). However, it may not be appropriate to evaluate the success of blinding procedures simply by comparing them to chance. People who experience positive outcomes may guess that they are in the treatment group and those who experience satisfactory or unsatisfactory outcomes may presume they are in the PLA group (Boutron *et al*., 2005). In the context of this study, if participants felt more 'energised' during one trial it may have prompted them to choose this as the treatment, despite being unable to distinguish between solutions by taste, smell, colour or texture. This did appear to occur in some of the participants in this study. Obviously, this method of solution choice cannot be blinded. Therefore, it may be beneficial in future work to ask participants to identify the solution immediately after consuming the pre-exercise bolus, and again at the end of the exercise bout. This may enable observation of any influence of factors such as the perception of exercise performance or difficulty on solution choice (Beedie *et al*., 2007).

4.4.8 Preliminary tests

Typical HR_{max} during incremental treadmill running to exhaustion in adolescents is reported to be between 195-210 beats per min (Armstrong, 2007). The mean HR_{max} recorded in the current study, coupled with the mean RPE score and consistent observation of subjective markers of fatigue, provides strong evidence that a maximal effort was generated by the participants.

4.5 Conclusion

Ingestion of a 6% CHO-E solution immediately before and during prolonged intermittent, high-intensity exercise significantly improves the intermittent endurance capacity of adolescent team games players. In contrast, CHO ingestion does not significantly influence sprint performance during prolonged intermittent, high-intensity exercise in these participants. While CHO supplementation did not influence physiological responses during part A of the exercise protocol, a significantly greater peak HR at exhaustion was recorded.

Chapter 5: The Influence of Ingesting a 2, 6, and 10% Carbohydrate-Electrolyte Solution Immediately Before, and During, Prolonged Intermittent, High-Intensity Exercise on the Intermittent Endurance Capacity, Sprint Performance, and Physiological Response of Adolescent Team Games Players

Abstract

This study investigated the influence of consuming a 2, 6, and 10% carbohydrate-electrolyte (CHO-E) solution on the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players. Seven participants (five males and two females; mean age 13.3 ± 0.5 years, height 171.2 ± 4.5 cm, body mass (BM) 62.0 ± 6.3 kg) performed three trials separated by 3–7 days. In each trial, they completed four 15-min periods of part A of the Loughborough Intermittent Shuttle Test (LIST) followed by an intermittent run to exhaustion (part B). Participants consumed 5 $ml.kg^{-1}$ BM of the solution during the 5-min pre-exercise period, and a further 2 $ml.kg^{-1}$ BM every 15 min during part A of the LIST. Intermittent endurance capacity increased by 34% with ingestion of the 6% CHO-E solution compared with the 10% solution (5.5 ± 0.8 vs. 4.1 ± 1.5 min, $P < 0.05$, $r =$ 076), equating to a distance of 931 ± 172 vs. 706 ± 272 m ($P < 0.05$, $r = 0.76$). There was no significant difference between the 2% (4.8 ± 1.2 min) and 6% ($P = 0.10$, $r =$ 0.63) or the 2 and 10% solutions ($P = 0.09$, $r = 0.63$). Carbohydrate concentration ([CHO]) did not significantly influence mean 15 m sprint time ($P = 0.38$, $r = 0.42$), peak sprint time ($P = 0.37$, $r = 0.42$), or heart rate (HR; $P = 0.23$, $r = 0.56$). These results suggest that the [CHO] of an ingested solution influences the intermittent endurance capacity of adolescent team games players with a 6% solution significantly more effective than a 10% solution.

5.1 Introduction

Study one of this thesis reported a significant 24% improvement in intermittent endurance capacity when adolescent team games players ingested a 6% CHO-E

solution before and during a modified LIST. This was achieved using the same BM-standardised ingestion volumes and timings as the pioneering adult work of Nicholas *et al*. (1995). The lack of a significant treatment effect on HR, RPE, SR or BM loss in the first thesis study also mirrored the findings of most related adult work (Ali *et al*., 2007; Davis *et al*., 1999; Nicholas *et al*., 1995). This indicates that the relative physiological responses to prolonged intermittent, high-intensity exercise with CHO ingestion appear similar between adolescents and adults.

Most previous adult studies showing improved intermittent endurance capacity with CHO ingestion during prolonged intermittent, high-intensity exercise used [CHO] of 6.0-6.4% (60-64 $g.L^{-1}$ of solution, Davis *et al*., 1999; Foskett *et al*., 2008; Nicholas *et al*., 1995). This is in line with existing adult guidelines for CHO supplementation during prolonged steady-state exercise that recommend a CHO intake of ~1.0-1.1 $g.min^{-1}$ (60-70 $g.h^{-1}$, Jeukendrup, 2004) to maximise CHO_{exo} oxidation. However, it cannot be assumed that CHO ingestion guidelines for steady-state exercise will be the optimal guidelines for prolonged intermittent, high-intensity exercise. Christmass *et al*. (1999) demonstrated a 1.2 times higher ($P < 0.05$) rate of CHO_{endo} oxidation during 90 min of sustained intermittent compared with continuous running at the same overall $\dot{V}O_2$. This suggests that CHO ingestion requirements may be greater during intermittent compared with continuous exercise. To date, no published research has investigated the influence of consuming different [CHO] during prolonged intermittent, high-intensity exercise. Ali and Williams (2009) reported no benefit of ingesting CHO at a rate of 52 $g.h^{-1}$ on sprint performance during the LIST, but did report a significant improvement in sprint performance with ingestion of 32 g $CHO.h^{-1}$ (Ali *et al*., 2007). However, intermittent endurance capacity, where CHO ingestion most consistently exerts an effect during prolonged intermittent, high-intensity exercise, was not assessed in these studies.

No published, research-supported guidelines exist for CHO supplementation during prolonged intermittent, high-intensity exercise in adolescents. The findings of the first thesis study were generated despite one fewer drink period compared with adult work, as adolescents commonly play team games for a shorter duration than adults

(60 min *vs*. 90 min, Ekblom, 1986). As a result, mean CHO intake was 0.56 $g.min^{-1}$ compared with ~0.70-0.85 $g.min^{-1}$ (Nicholas *et al*., 1995; Welsh *et al*., 2002). While the shorter duration of adolescent team games may suggest a lesser depletion of CHO_{endo} stores, and therefore question the efficacy of CHO ingestion, it should be considered that adolescents may have lower endogenous glycogen stores than adults (Aucouturier *et al*., 2008), which may offset the sparing effect of a shorter exercise bout. Furthermore, BM-relative CHO_{exo} oxidation rates may be significantly greater in young people compared to adults (Timmons *et al*., 2003), despite the preferential use of fat as a fuel source in young people (Timmons *et al*., 2007[a]). The different metabolic response of young people to exercise indicates that adult guidelines regarding CHO ingestion before and during exercise may not be appropriate for this population. It would be of interest to study the influence of different rates of CHO ingestion by young people during prolonged intermittent, high-intensity exercise, to observe whether their ability to readily oxidise CHO_{exo} elicits a dose-response relationship to CHO provision in terms of enhancing exercise performance. This would also begin the process of forming guidelines for the ingestion of CHO during prolonged intermittent, high-intensity exercise in this population.

Manipulating CHO_{exo} intake could be achieved by ingesting different volumes of a 6% solution; however, ingesting larger volumes may lead to GI distress (Shi & Gisolfi 1998). Furthermore, this practice would not translate well to actual field-based team games, where there are limited opportunities to drink during matches (Clarke *et al*., 2008). Manipulating the [CHO] of the ingested solution may also increase the risk of GI distress (Shi *et al*., 2004), but the minimal understanding of CHO tolerance during team games in adolescents, along with the absence of any CHO intake guidelines, provides a rationale for using different [CHO].

Research Question: Does the carbohydrate concentration of a solution ingested immediately before and during prolonged intermittent, high-intensity exercise influence the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players?

Hypothesis 1: Carbohydrate concentration will significantly influence the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 2: Carbohydrate concentration will not significantly influence the repeated 15 m sprint performance of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 3: Carbohydrate concentration will not significantly influence the physiological response, as measured by HR, SR and BM loss, of adolescent team games players during prolonged intermittent, high-intensity exercise.

5.2 Methods

In addition to the general methods chapter (chapter 3), this section describes the exact protocols used, as well as any procedures or measurements exclusive to this study.

5.2.1 Participants

Seven team games players (five males and two females) participated in the study. All participants also completed the first thesis study (chapter 4). Physical and biological characteristics are in table 5.1.

Table 5.1 Physical and biological characteristics of participants. Data are mean ± SD (range).

	Age (years)	**Height (cm)**	**Body Mass (kg)**	**Maturity Offset (years)**
All participants (*n* = 7)	13.3 ± 0.5 (13-14)	171.2 ± 4.5 (163.0-177.1)	62.0 ± 6.3 (54.8-71.2)	+1.25 (+0.62-+2.68)

5.2.2 Preliminary tests

5.2.2.1 Peak running velocity

On their first visit to the laboratory, participants performed a treadmill familiarisation and V_{peak} test followed by a familiarisation of the LIST protocol, as described in section 3.2.1.

5.2.3 Experimental design

Each participant completed the following three trials:

A. 2% CHO-E solution (20 g CHO.L^{-1} solution; low CHO trial – LCHO)
B. 6% CHO-E solution (60 g CHO.L^{-1} solution; moderate CHO trial – MCHO)
C. 10% CHO-E solution (100 g CHO.L^{-1} solution; High CHO trial – HCHO)

Solution compositions were as follows:

2% carbohydrate-electrolyte solution

The solution was 1 L^{-1} of water mixed with 20 g of CHO powder (100% maltodextrin; High5 Ltd, Bardon, UK) and two dissolvable electrolyte tablets (High5 Ltd, Bardon, UK). Total electrolyte composition of the solution was: Na^+, 250 mg; magnesium, 60 mg; K^+, 90 mg; calcium, 20 mg.

6% carbohydrate-electrolyte solution

The solution was 1 L^{-1} of water mixed with 60 g of CHO powder (100% maltodextrin) and two dissolvable electrolyte tablets. Total electrolyte composition of the solution was: Na^+, 250 mg; magnesium, 60 mg; K^+, 90 mg; calcium, 20 mg.

10% carbohydrate-electrolyte solution

The solution was 1 L^{-1} of water mixed with 100 g of CHO powder (100% maltodextrin) and two dissolvable electrolyte tablets. Total electrolyte composition of the solution was: Na^+, 250 mg; magnesium, 60 mg; K^+, 90 mg; calcium, 20 mg.

As discussed in section 4.2.3, the electrolyte tablets contained artificial sweetner (Saccharine and Acesulfame K) and were flavoured as citrus, berry, or cherry-orange. Within-participants, all solutions were matched for colour, taste, texture, and feeling within the mouth. Pilot work confirmed that the artificially sweetened electrolyte tablets were an effective blinding agent.

The solutions were chosen so that they contained notably different amounts of CHO, and were comparable to solutions used in prior related research and/or those widely available to athletes. The LCHO solution was similar in concentration to commercially available CHO-E drinks. The MCHO solution was the same [CHO] used in study 1 and was very similar to solutions used in the majority of adult work (Davis *et al*., 1999; Nicholas *et al*., 1995; Welsh *et al*., 2002, table 2.7), as well as a wide range of commercially available CHO-E solutions. The HCHO solution was employed as solutions with a [CHO] >10% are rarely used in contemporary research due to current adult guidelines regarding fluid and CHO intake during prolonged, steady-state exercise (Jeukendrup, 2004). No such guidelines currently exist for young people. Therefore, the use of a [CHO] greater than 10% currently has no support and, due to the lack of knowledge of CHO tolerance during prolonged intermittent exercise in young people, no ethical basis.

5.2.4 Experimental protocol

Participants arrived at the laboratory in a fed, post-prandial state. For logistical reasons, it was not possible to test all participants at the same time of day, but within-participants sessions were completed at the same time of day or as near as possible. Sessions began between 10am and 6pm. In each trial, participants performed the

LIST protocol as detailed in section 3.2.2 and figure 3.4, and consumed the appropriate solution as described in section 4.2.4. In this study, participants were asked to state which solution they believed was prescribed immediately after consumption of the pre-exercise bolus before beginning the LIST, and again after measurement of post-exercise BM. This was done in order to compare their responses and observe whether their experiences during the exercise bout prompted them to change their mind about which solution they had consumed during the protocol. Participants' were clearly informed that they were free to change their mind from their pre-exercise solution selection, or to keep it the same.

5.2.5 Measurements

All measurements made during the study are detailed in section 3.3.

5.2.6 Statistical analysis

In addition to the statistical analysis detailed in section 3.4, the following analyses were completed. One-way repeated measures ANOVA compared between-trials differences in fluid and CHO intake, pre-exercise BM, BM loss and SR, distance covered in part A and B, and time to exhaustion, HR, RPE, GF and GD at exhaustion in part B. Simple contrast analysis was used to explore main effects of time to exhaustion and distance covered in part B, and Bonferroni pairwise comparisons to investigate main effects of fluid and CHO intake, respectively. Two way (solution x time) ANOVA analysed mean relative humidity, mean sprint times and mean peak sprint times, HR, RPE, GF and GD during part A. Bonferroni pairwise comparisons explored the main effect for RPE, and paired *t*-tests with Bonferroni correction explored main effects for mean sprint times, mean peak sprint times, HR, GF and GD. Friedman tests with Bonferroni correction analysed between trials differences in mean ambient temperature at all time points, with a Friedman's test employed to analyse the main effect of time for the grouped trials data. Chi-square analysis assessed the frequency distribution of solution choice responses. Unless specified, data are mean ± SD.

5.3 Results

5.3.1 Preliminary tests

Mean V_{peak} attained in the incremental treadmill run to exhaustion was 14.4 ± 1.2 $km.h^{-1}$. Mean HR_{max} and RPE at exhaustion were 196 ± 6 beats per min and 9.3 ± 0.5, respectively.

5.3.2 Distance covered and time to exhaustion

By design, distance covered during part A of the LIST was the same in all three trials (7.1 ± 0.3 km). Time to exhaustion during part B for all trials is shown in figure 5.1, with time to exhaustion for each individual participant shown in figure 5.2. Time to exhaustion was significantly influenced by solution ($F_{2, 12}$ = 6.1, P < 0.05, r = 0.71), and was 34.1% greater in the MCHO trial compared with the HCHO trial (P < 0.05, r = 0.76) and by 14.6% compared with the LCHO trial, although this was not statistically significant (P = 0.10, r = 0.63). Time to exhaustion in the LCHO trial was 17.1% greater than the HCHO trial, but was not statistically significant (P = 0.09, r = 0.63). Distance covered in part B was significantly greater in the MCHO trial compared with the HCHO trial (931 ± 172 vs. 706 ± 272 m, P < 0.05, r = 0.76), but not the LCHO trial (811 ± 230 m, P = 0.09, r = 0.63). Distance covered was not significantly different between the LCHO and HCHO trials (P = 0.11, r = 0.61).

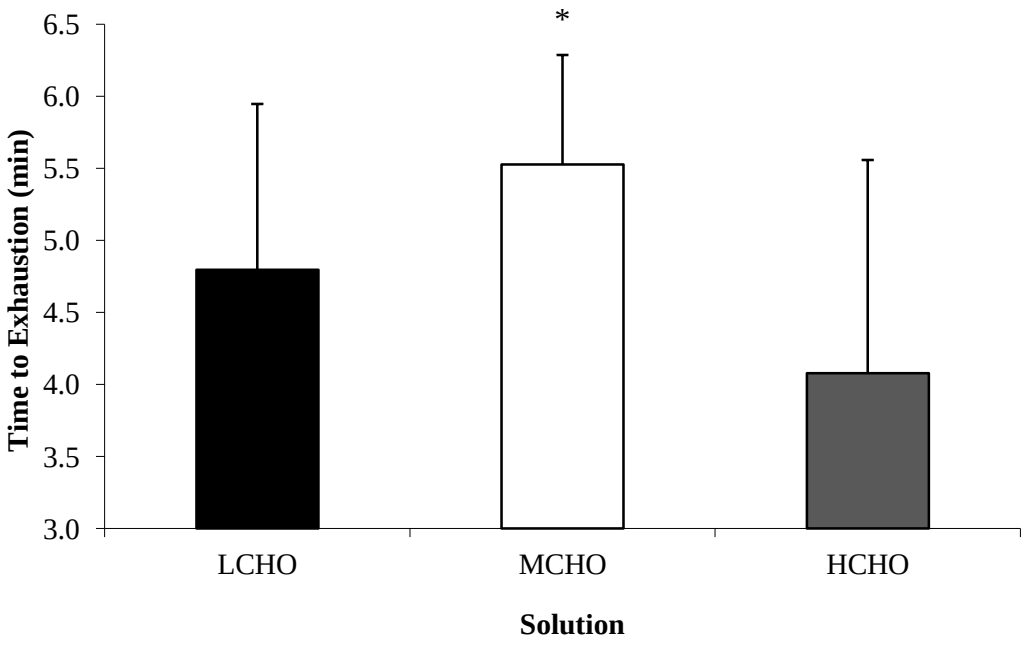

Figure 5.1 Time to exhaustion (min) during part B of the Loughborough Intermittent Shuttle Test for all trials. * significantly greater than the HCHO trial, $P < 0.05$. Data are mean ± SD ($n = 7$).

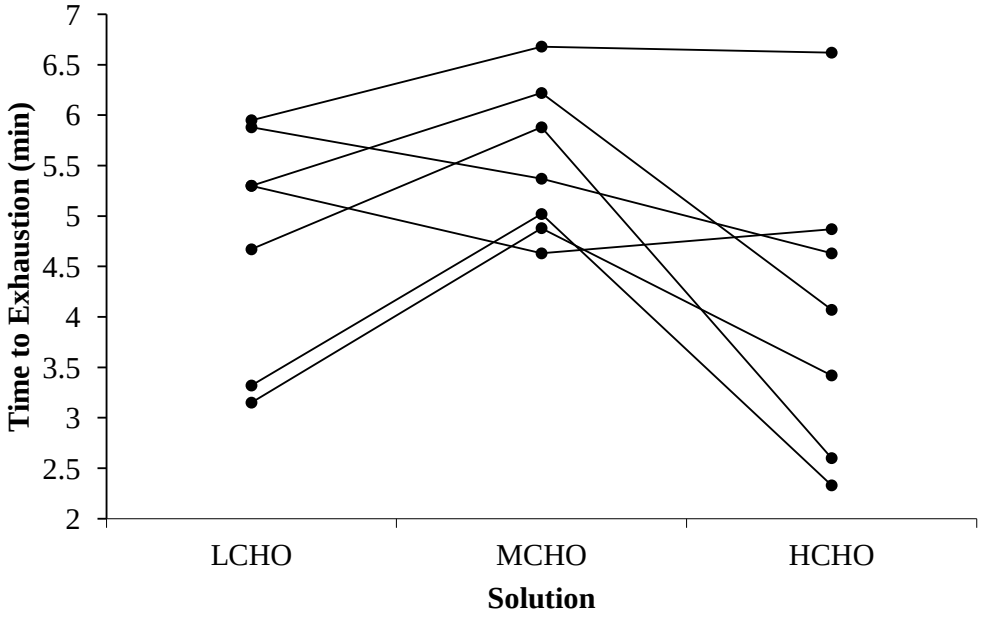

Figure 5.2 Time to exhaustion (min) during part B of the Loughborough Intermittent Shuttle Test for each participant in all trials ($n = 7$).

5.3.3 Sprint times

The mean time of all sprints, and the mean of participants' peak sprint time only, in each block of part A of the LIST are shown in figure 5.3A and 5.3B, respectively. There was a trend for mean sprint times to be slower throughout exercise in the HCHO trial compared with the other two trials, but no main effect of solution was present ($F_{2, 10}$ = 1.1, P = 0.38, r = 0.42). Similarly, there was no interaction effect (solution x time, $F_{2.1, 10.3}$ = 0.89, P = 0.44, r = 0.39). There was a main effect of time ($F_{1.1, 5.5}$ = 8.6, P < 0.05, r = 0.79), with sprint time increasing significantly with each successive exercise block (P < 0.05, r = 0.56, 0.82 and 0.55, respectively). Peak sprint time for each exercise block showed a trend for slower times in the HCHO trial compared with the other two trials, but no main effect of solution ($F_{2, 10}$ = 1.1, P = 0.37, r = 0.42) or interaction ($F_{6, 30}$ = 0.6, P = 0.72, r = 0.33) was found. There was a main effect of time ($F_{3, 15}$ = 8.3, P < 0.005, r = 0.79), with peak sprint time significantly slower in block 3 than block 2 (P < 0.001, r = 0.75). There was no significant difference between blocks 1 and 2 (P = 0.22, r = 0.30) or 3 and 4 (P = 0.60, r = 0.10).

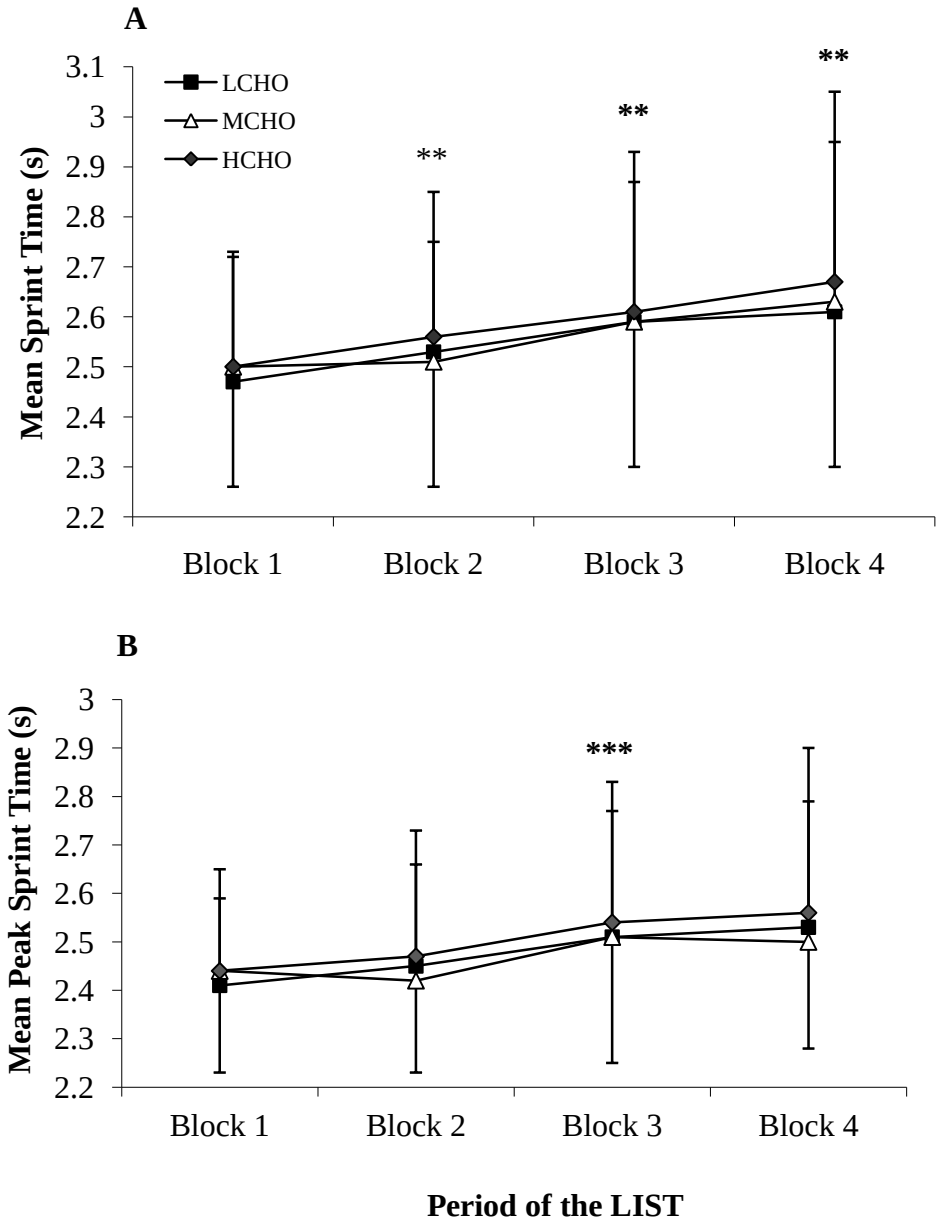

Figure 5.3 Mean sprint time (s, A) and mean peak sprint time (s, B) during part A of the Loughborough Intermittent Shuttle Test for all trials. Data are mean ± SD (n = 6). ** significantly greater than previous block, $P < 0.05$; *** significantly greater than previous block, $P < 0.001$.

5.3.4 Heart rate, ratings of perceived exertion and gastric disturbances

Mean HR and RPE during part A of the LIST, and mean peak HR and mean RPE at exhaustion in part B are shown in table 5.2. Heart rate showed a trend to be lower in

the LCHO trial at all time points in part A, but there was no significant treatment ($F_{2, 8}$ = 1.8, P = 0.23, r = 0.56) or interaction ($F_{6, 24}$ = 1.7, P = 0.62, r = 0.40) effect. There was a main effect of time for HR in part A ($F_{3, 12}$ = 32.1, P < 0.001, r = 0.94). Heart rate in block 2 was significantly greater than block 1 (P < 0.01, r = 0.98). There was no significant difference between blocks 2 and 3 (P = 0.48, r = 0.76) or 3 and 4 (P = 1.0, r = 0.22). Peak HR at exhaustion in part B was not significantly different between trials ($F_{1.1, 6.8}$ = 0.67, P = 0.46, r = 0.32). Ratings of perceived exertion were similar at all time points between trials, with no significant differences found ($F_{2, 12}$ = 1.3, P = 0.32, r = 0.42). No interaction effect was present ($F_{6, 36}$ = 0.3, P = 0.53, r = 0.35). There was a main effect of time ($F_{1.1, 6.5}$ = 36.0, P < 0.005, r = 0.93), with RPE significantly greater in block 2 than block 1 (P < 0.05, r = 0.97) and in block 4 than block 3 (P < 0.001, r = 0.99). There was no significant difference between blocks 2 and 3 (P = 0.41, r = 0.95), and no significant between trials difference at exhaustion ($F_{1, 6}$ = 1.0, P = 0.36, r = 0.38).

Table 5.2 Mean heart rate (beats per min) and mean ratings of perceived exertion during part A of the Loughborough Intermittent Shuttle Test, and mean peak heart rate and mean ratings of perceived exertion at exhaustion in part B for all trials. Data are mean ± SD (n = 7).

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean heart rate (beats per min)					
LCHO	159 ± 7	164 ± 7†	165 ± 7	165 ± 7	189 ± 3
MCHO	162 ± 6	168 ± 5†	170 ± 6	169 ± 5	190 ± 4
HCHO	162 ± 5	168 ± 6†	168 ± 6	168 ± 5	190 ± 4
Mean ratings of perceived exertion					
LCHO	4.6 ± 1.1	6.0 ± 0.8**	7.4 ± 1.0	7.6 ± 1.1***	9.4 ± 0.5
MCHO	4.4 ± 1.0	6.1 ± 0.7**	6.7 ± 1.0	8.0 ± 0.8***	9.3 ± 0.5
HCHO	4.4 ± 1.0	6.0 ± 1.0**	7.1 ± 0.7	8.0 ± 0.8***	9.3 ± 0.5

LCHO = low CHO trial; MCHO = moderate CHO trial; HCHO = high CHO trial
† significantly greater than block 1, $P < 0.01$; ** significantly greater than previous block, $P < 0.05$; *** significantly greater than previous block, $P < 0.001$

Mean GF and GD during part A of the LIST and at exhaustion in part B are shown in table 5.3. Mean GF was not significantly influenced by solution ($F_{2, 12} = 1.1$, $P = 0.36$, $r = 0.40$), and there was no interaction effect ($F_{6, 36} = 1.0$, $P = 0.43$, $r = 0.38$). There was a significant effect of time on GF ($F_{3, 18} = 3.3$, $P < 0.05$, $r = 0.59$). This main time effect was just under the stated alpha figure, and specific differences between time points could not be determined using *post hoc* analyses. Effect sizes for the differences between blocks 1 and 2, 2 and 3, and 3 and 4 were $r = 0.10$, 0.22 and 0.48, respectively. Gut fullness at exhaustion was not significantly different between trials ($F_{2, 12} = 2.2$, $P = 0.16$, $r = 0.51$). Despite the significant main effect of time, GF scores during part A of the LIST were modest. There was no treatment ($F_{2,}$

$_{12}$ = 0.4, P = 0.68, r = 0.25) or interaction ($F_{6, 36}$ = 1.8, P = 0.14, r = 0.48) effect on GD, but there was a main effect of time ($F_{3, 18}$ = 3.9, P < 0.05, r = 0.63). As with GF, specific differences could not be determined *post hoc*. Effect sizes for the differences between blocks 1 and 2, 2 and 3, and 3 and 4 were r = 0.46, 0.10 and 0.40, respectively. Gastric discomfort at exhaustion was similar across all trials ($F_{2, 12}$ = 0.27, P = 0.77, r = 0.21). Gastric discomfort scores during part A of the LIST were moderate.

Table 5.3 Mean gut fullness and gastric discomfort ratings during part A of the Loughborough Intermittent Shuttle Test, and at exhaustion in part B, for all trials. Data are mean ± SD (n = 7).

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean gut fullness ratings					
LCHO	4.1 ± 1.7	4.7 ± 1.3	4.7 ± 1.1	5.3 ± 1.3	5.1 ± 1.1
MCHO	4.1 ± 1.6	3.9 ± 1.9	4.0 ± 1.7	4.7 ± 1.7	5.3 ± 1.3
HCHO	3.7 ± 1.4	3.7 ± 1.1	4.3 ± 1.6	4.3 ± 1.1	4.7 ± 0.8
Mean gastric discomfort ratings					
LCHO	2.1 ± 1.1	3.1 ± 1.2	3.0 ± 1.3	3.1 ± 1.5	4.0 ± 1.5
MCHO	2.9 ± 1.3	3.3 ± 1.4	3.3 ± 1.6	3.4 ± 1.7	4.3 ± 1.8
HCHO	2.3 ± 1.9	2.4 ± 1.1	2.9 ± 1.2	4.0 ± 1.9	4.1 ± 2.0

LCHO = low CHO trial; MCHO = moderate CHO trial; HCHO = high CHO trial
A main effect of time was found for GF and GD (P < 0.05)

5.3.5 Body mass loss and sweat rate

Mean pre-exercise dry nude BM was not significantly different between trials ($F_{2, 12}$ = 0.1, P = 0.92, r = 0.11). Mean BM loss was 1.0 ± 0.2, 1.0 ± 0.2, and 1.0 ± 0.4 kg

in the LCHO, MCHO and HCHO trials, respectively ($F_{2, 12}$ = 0.11, P = 0.90, r = 0.13). This equates to a mean loss of 1.62 ± 0.37, 1.63 ± 0.24, and 1.54 ± 0.49% of pre-exercise BM, respectively ($F_{2, 12}$ = 0.24, P = 0.79, r = 0.19). Mean SR was 0.78 ± 0.15, 0.78 ± 0.13, and 0.76 ± 0.28 $L.h^{-1}$ in the LCHO, MCHO and HCHO trials, respectively ($F_{2, 12}$ = 0.03, P = 0.97, r = 0.07), equating to a BM-relative mean sweat loss of 12.63 ± 2.81, 12.53 ± 1.75, and 12.18 ± 3.86 $ml.kg^{-1}$ $BM.h^{-1}$, respectively ($F_{2, 12}$ = 0.09, P = 0.91, r = 0.12).

5.3.6 Blinding

Figure 5.4 details the number of participants who gave correct and incorrect solution choices pre- and post-exercise for each trial. After consuming the initial bolus of solution immediately prior to exercise, one participant (14%) correctly identified all solutions and six (86%) failed to do so. Chi square analysis of the pre-exercise responses in the MCHO trial found a non-significant deviation from the expected response frequency ($\chi^2(1)$ = 3.6, P = 0.16). Post-exercise, only one participant correctly guessed all three solutions, and this was the same participant who guessed all three correctly pre-exercise. In the LCHO trial, one participant (14%) correctly guessed the solution post-exercise when they had guessed incorrectly prior to exercise. One participant (14%) chose the incorrect solution when they had chosen correctly pre-exercise. In the MCHO trial, one participant (14%) chose the correct solution post-exercise when they had chosen incorrectly pre-exercise. No participants chose the incorrect solution after having been correct pre-exercise. In the HCHO trial, no participants chose the correct solution post-exercise after having chosen incorrectly pre-exercise. Three participants (43%) chose the incorrect solution after choosing correctly pre-exercise.

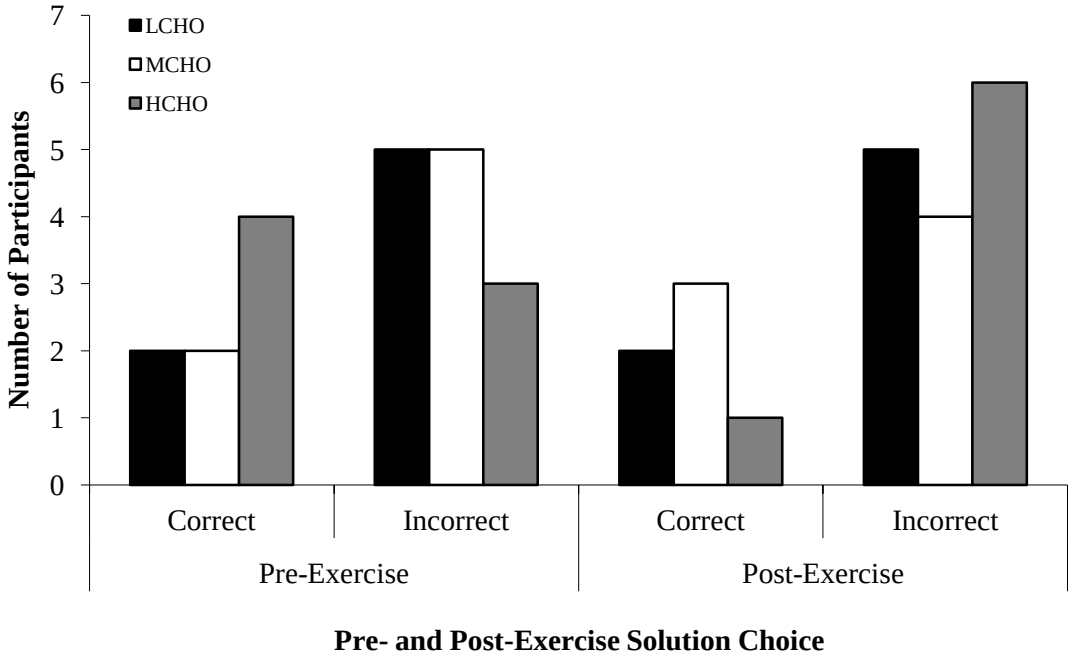

Figure 5.4 Number of participants who made correct and incorrect solution choices pre- and post-exercise for each trial.

5.3.7 Fluid and carbohydrate intake

Mean fluid intake was 811 ± 83, 810 ± 82, and 810 ± 84 ml ($F_{2, 12}$ = 0.05, P = 0.95, r = 0.09) in the LCHO, MCHO and HCHO trials, respectively. Absolute CHO intake in the LCHO, MCHO and HCHO trials was 12.7 ± 1.3, 37.6 ± 3.7, and 64.0 ± 7.3 $g.h^{-1}$ ($F_{1.0, 6.1}$ = 497.0, P < 0.001, r = 0.99), or 0.21 ± 0.02, 0.63 ± 0.06, and 1.07 ± 0.02 $g.min^{-1}$ ($F_{1.0, 6.1}$ = 481.6, P < 0.001, r = 1.0). Body mass-relative CHO consumption for the duration of the protocol was 0.26, 0.78, and 1.3 $g.kg^{-1}$ BM in the LCHO, MCHO and HCHO trials. Relative to the amount of CHO ingested in the first hour of exercise, it was 0.20, 0.60, and 1.02 $g.kg^{-1}$ $BM.h^{-1}$ in the LCHO, MCHO and HCHO trials, respectively.

5.3.8 Ambient temperature and relative humidity

Mean ambient temperature and relative humidity during the LIST are shown in table 5.4. Mean ambient temperature was not significantly different between trials at any

time point, therefore the data for all three trials was grouped for analysis of a main effect of time. Mean ambient temperature rose by 0.3°C between the onset of exercise and the end of part A of the LIST ($\chi^2(4) = 39.3$, $P < 0.001$). Mean relative humidity was not significantly different between ($F_{2, 12} = 0.06$, $P = 0.94$, $r = 0.10$) or within ($F_{1.6, 9.6} = 4.1$, $P = 0.06$, $r = 0.64$) trials, and there was no interaction effect ($F_{2.2, 2.4} = 0.90$, $P = 0.46$, $r = 0.36$).

Table 5.4 Mean ambient temperature (°C) and relative humidity (%) immediately before, and during, part A of the Loughborough Intermittent Shuttle Test for all trials. Data are mean ± SD ($n = 7$).

	Period of the LIST				
	Pre-exercise	Block 1	Block 2	Block 3	Block 4
Mean ambient temperature (°C)					
LCHO	18.0 ± 1.8	18.1 ± 1.9	18.1 ± 1.9	18.2 ± 1.9	18.2 ± 1.9
MCHO	17.8 ± 1.4	17.9 ± 1.4	18.0 ± 1.4	18.0 ± 1.3	18.1 ± 1.3
HCHO	18.3 ± 2.2	18.4 ± 2.1	18.4 ± 2.1	18.5 ± 2.1	18.5 ± 2.1
Mean relative humidity (%)					
LCHO	40.6 ± 5.5	40.1 ± 6.1	39.9 ± 6.1	39.4 ± 5.9	39.0 ± 6.0
MCHO	40.7 ± 8.4	40.4 ± 8.4	40.1 ± 8.6	39.7 ± 8.6	39.6 ± 9.2
HCHO	40.6 ± 9.0	41.0 ± 8.3	41.1 ± 8.2	41.0 ± 8.3	40.0 ± 8.8

LCHO = low CHO trial; MCHO = moderate CHO trial; HCHO = high CHO trial

A main effect of time was found for the grouped mean ambient temperature data ($P < 0.001$).

5.4 Discussion

The results of this study demonstrate that ingestion of a 6% CHO-E solution immediately before, and during, prolonged intermittent, high-intensity exercise

significantly increases the intermittent endurance capacity of adolescent team games players compared with a 10% solution. A non-significant trend for improved intermittent endurance capacity with the 6% compared with a 2% solution, and the 2% compared with a 10% solution, was also found. Carbohydrate concentration has no significant influence on repeated sprint performance or physiological responses during prolonged intermittent, high-intensity exercise in adolescent team games players.

5.4.1 Time to exhaustion

As discussed in section 5.1, no guidelines exist for CHO ingestion during team games exercise in children or adults. Adult recommendations state that a CHO ingestion rate of 60-70 $g.h^{-1}$, or 1-1.1 $g.min^{-1}$, is optimal for maximising CHO_{exo} oxidation during moderate to high-intensity steady-state exercise (section 2.3.2 & 2.3.3). The data from the current study suggests that these adult guidelines do not apply to 12-14 year old team games athletes during prolonged intermittent, high-intensity exercise, as the greatest intermittent endurance capacity was achieved in the MCHO trial, with a mean CHO ingestion rate notably lower than the above recommendations (section 5.3.7). However, CHO ingestion rates between adults and young people should perhaps be compared relative to BM. In this situation, the CHO ingestion rate by the young people in this study (0.60 $g.kg^{-1}$ $BM.h^{-1}$) is still ~32% lower than that of some adult work demonstrating maximal CHO_{exo} oxidation rates with CHO ingestion rates of ~60 $g.h^{-1}$ (0.88-0.91 $g.kg^{-1}$ $BM.h^{-1}$; Jeukendrup *et al*., 1996[a]; Pirnay *et al*., 1982; Wagenmakers *et al*., 1993). In support of this child-adult difference, Nassis *et al.* (1998) failed to find a significant improvement in intermittent endurance capacity in adults during prolonged intermittent treadmill running with ingestion of CHO at very similar rates to that of the MCHO trial in the current study (0.6 $g.min^{-1}$; 34 $g.h^{-1}$, section 2.3.4, table 2.6).

The minimum absolute rate of CHO ingestion that has been demonstrated to enhance endurance capacity during prolonged cycling in adults is 16 $g.h^{-1}$ (Maughan *et al*., 1996) whereas any further CHO ingestion above a rate of ~1-1.1 $g.min^{-1}$ does not

further increase the rate of CHO_{exo} oxidation, provided the composition of ingested CHO remains the same (Jeukendrup, 2004). In the current study, the CHO ingestion rate in the LCHO trial may not have facilitated absorption of sufficient CHO from the intestine into the systemic circulation to facilitate exercise enhancement (Shi & Passe, 2010). This is supported by Rogers *et al*. (2005), who reported significantly lower total CHO absorption during prolonged steady-state exercise with ingestion of a 3% CHO-E solution compared with a 6% solution. In contrast, the greater ingestion rate in the HCHO trial may have failed to generate greater CHO absorption and oxidation rates compared with the MCHO trial. Studies that have manipulated the amount of ingested CHO during steady-state exercise demonstrate both a negligible effect of ingesting large amounts of CHO (2.4-3.0 $g.min^{-1}$) on exogenous oxidation rates and a reduction in the percentage contribution of CHO_{exo} to overall CHO oxidation rate (oxidation efficiency; Jeukendrup *et al*., 1999; Rehrer *et al*., 1992) such that CHO_{exo} oxidation does not exceed 1-1.1 $g.min^{-1}$. However, if CHO ingestion in the HCHO trial simply exceeded the maximal rate of CHO absorption and/or oxidation of the participants, a similar intermittent endurance capacity between the HCHO and MCHO trials would have been expected (Murray *et al*., 1987; Murray *et al*., 1989). This requires further study, perhaps by focussing initially on potential modulators of CHO_{exo} oxidation such as exercise intensity, muscle glycogen concentration, training status, the rate of digestion, absorption and transport of glucose, and the degree of saturation of intestinal CHO transporters (Jeukendrup, 2004; Shi & Passe, 2010). It should also be noted that there was a larger variation in time to exhaustion values for the HCHO trial, perhaps representing a greater individual variation in response to this CHO dose. Conversely, this may also have been due to the relatively small sample size. While this study was not designed to identify enhancement mechanisms, it does provide initial indirect support for the existence of low and high CHO ingestion thresholds during intermittent endurance running in adolescents, below and above which the efficacy of CHO does not appear to be maximised, in line with adult findings (Jeukendrup, 2004). Interestingly, these thresholds appear to be at different ingestion rates for adolescents than adults. Clearly, more work is required to confirm the relative influence of different [CHO] during prolonged intermittent, high-intensity exercise in

adolescents, and to provide data on the metabolic response to these [CHO], which may help to explain the performance data.

In the current study, the improvement in intermittent endurance capacity in the MCHO compared with the HCHO trial is greater than the 24.4% improvement reported in study 1 (chapter 4) between a 6% CHO-E solution and a PLA. This may be related to the maturational status of the participants in the two studies. Participants in the current study had a mean maturity offset of +1.25 years from PHV, compared with +0.51 years in study 1. A potential maturation-related attenuation of fat metabolism and greater utilisation of CHO (Timmons *et al*., 2007[a]) may have facilitated the greater between-trials difference observed in the current study. However, this is speculative due to the absence of metabolic data, and the reported accuracy of the maturity offset equations (section 3.2.3). It should be considered that study 1 remains the only other study to investigate ingestion of a CHO-E solution on the intermittent endurance capacity of adolescents during prolonged intermittent, high-intensity exercise. Therefore, the potential range of endurance capacity enhancement that CHO may afford adolescents is unknown, particularly when it is considered that the maturational status of different adolescent populations may influence the degree of enhancement. This is reinforced by the findings of related adult work, where improvements in intermittent endurance capacity range from 33-52% (Davis *et al*., 1999; Nicholas *et al*., 1995). However, the above discussion should be considered with reference to the point that participants in the current study began exercise in a fed, post-prandial state. Pre-exercise nutritional status can alter substrate use and exercise performance, as well as the effect of CHO ingested during exercise (Chryssanthopoulos & Williams, 1997; Coyle *et al*., 1985; Neufer *et al*., 1987). Therefore, between-study differences in the pre-exercise nutritional status of participants cannot be discounted, and may have contributed to the different percentage improvements in intermittent endurance capacity between this and the previous study.

While the differences in intermittent endurance capacity between the LCHO and MCHO, and the LCHO and HCHO trials, were not statistically significant, large ES

were reported for these differences. Participant numbers in the current study may not have been sufficient for these differences to reach significance.

5.4.2 Sprint performance

The absence of a significant treatment effect on sprint performance is in line with study 1 (section 4.4.2). Low muscle glycogen concentration (< ~200 mmol.kg^{-1} d.w.) can attenuate sprint performance during soccer (Bangsbo *et al*., 2006). When muscle glycogen levels are not significantly compromised, [PCr] and its rate of resynthesis are more related to short-duration sprint performance than CHO (Spencer *et al*., 2006). Participants in this study were asked to follow their normal diet and to refrain from heavy exercise for 24 and 48 h prior to each trial, respectively; therefore, muscle glycogen may not have reached a critical level in any trial where CHO ingestion would have influenced sprint performance. This is supported by the lack of between-trials difference for mean sprint duration and mean peak sprint duration at any time point during the LIST.

The progressive increase in mean sprint time over the duration of the LIST is in agreement with study 1 and provides further evidence that CHO supplementation does not facilitate improvements in sprint performance during prolonged intermittent, high-intensity exercise in adolescents. Possible reasons for this progressive increase in sprint time are discussed in section 4.4.2. The mean increase in sprint time from the first to the last block of part A in all trials is greater than that recorded in some adult work (0.08 s for both trials; Ali *et al*., 2007), but less than that reported in study 1 (section 4.3.3). This provides further confirmation that adolescent team games players do not display a greater fatigue resistance than adults during sprinting in the LIST. It also suggests that adolescent team games sprinting performance may display similar inconsistencies to that of adult work which demonstrates a significantly better maintenance of sprint performance with CHO supplementation (Ali *et al.,* 2007; Welsh *et al.,* 2002), stable sprint performance (Nicholas *et al*., 1995; Nicholas *et al*., 1999; Winnick *et al*., 2005) and a treatment-independent attenuation of sprint performance over time (Foskett *et al*., 2008).

Factors such as maturation status, training status, motivation, and the use of males and females may help to explain the variation in sprint time attenuation.

5.4.3 Heart rate and ratings of perceived exertion

The lack of a treatment effect on HR during part A of the LIST in the current study agrees with study 1 (section 4.3.4) and most adult research (Ali *et al*., 2007; Nicholas *et al*., 1995; Welsh *et al*., 2002). However, the large ES for the main effect of treatment does suggest a practical influence of [CHO] on HR, and with the trend for a lower HR in the LCHO trial, indicates that the potential difference may lie between the LCHO trial and the other two trials. Repeating the study with a larger participant number may enable quantification of this. Once again, the significant increase in HR from block 1 to block 2 of the LIST, with no other significant differences, agrees with study 1 (section 4.3.4). Mean HR during part A of the LIST was in agreement with values reported during outdoor 11-a-side and indoor 5-a-side soccer matches in recreational and elite young players (Castagna *et al*., 2007; Strøyer *et al*., 2004, section 2.2.2.3.1), in line with study 1 (section 4.4.3).

Heart rate at exhaustion in part B of the current study was almost identical between trials. This is in contrast to study 1, which reported a significantly greater HR at exhaustion in the CHO trial (section 4.3.4). It is possible that this finding was simply an artefact of the particular participant population used in study 1 and not, as suggested, a mechanistic indicator of a metabolic and/or perceptual response to CHO supplementation (section 4.4.3). As the participants in the current study all took part in study 1, it could be speculated that a maturational influence may have contributed to the different HR findings between the two studies. However, this cannot be confirmed. Alternatively, a perceptual mechanism of CHO efficacy in adolescent team games players may exist, but might be participant-dependent. More work should be undertaken to clarify this.

Data from the current study further suggests that CHO supplementation does not modulate RPE during prolonged intermittent, high-intensity exercise in adolescents

(sections 4.3.4 & 4.4.3), although it should be considered that a non-CHO trial was not included in the current study. This indicates that enhancements in intermittent endurance capacity with CHO ingestion in this population are of a metabolic nature. The significant increase in RPE with time in the current study is similar to the findings from study 1 (section 4.3.4) and adult work (Ali *et al*., 2007; Nicholas *et al*., 1995). The difference in the current study is that no increase in RPE was observed in block 3 of part A of the LIST. This was not found in study 1, and has not been observed in any adult work. Both mean sprint and mean peak sprint times significantly slowed during block 3 of the LIST, which may have had an attenuating influence on RPE in block 3. However, a slower sprint time may relate to a less favourable metabolic condition for sprinting (Bangsbo *et al*., 2006), not necessarily a reduced effort from participants. Furthermore, in study 1 mean sprint and mean peak sprint time slowed significantly in block 3 of the LIST, but no corresponding attenuation in RPE was observed. The non-significant increase in RPE in block 3 of the LIST in the current study may be a result of the low participant number, which is supported by the almost perfect ES for this time point.

5.4.4 Gut fullness and gastric discomfort

The lack of a treatment effect, coupled with a main effect of time, for GF and GD in the current study is in general agreement with study 1 (section 4.3.4). Shi *et al.* (2004) found a significant increase in ratings of stomach upset and side ache with ingestion of an 8% CHO-E solution compared with a 6% solution during intermittent, high-intensity circuit training. Despite this significant increase, all ratings of GI discomfort were modest in both trials, which is in agreement with the current study. As discussed in study 1, the treatment-independent increase in GF and GD with time in the current study indicates that these increases were due to factors other than the ingested solutions (section 4.4.5). It therefore appears that 2, 6 and 10% CHO-E solutions are equally well tolerated by adolescents during prolonged intermittent, high-intensity exercise. This is further supported by the effectiveness of the blinding procedures in this study (section 5.4.6). Interestingly, a large ES was reported for GF at exhaustion between trials, with GF lower in the HCHO trial

(section 5.3.4 & table 5.3). This interesting finding could be due to participants terminating exercise as a result of other causes before the perception of GF reached higher levels. The potential influence of [CHO] on GF at exhaustion during prolonged intermittent, high-intensity exercise warrants further study.

5.4.5 Body mass loss and sweat rate

The non-significant between-trials difference in BM loss and SR in the current study is in agreement with study 1 (section 4.3.5). Furthermore, percentage BM loss and SR ($L.h^{-1}$ and $ml.kg^{-1}$ $BM.h^{-1}$) in the current study and study 1 are remarkably similar. When the results of these two studies are considered, it appears that ingestion of CHO across a range of concentrations does not alter the BM loss or SR responses of adolescents to prolonged intermittent, high-intensity exercise. Data on the absolute SR of 12-14 year old adolescents during exercise is lacking; however, the SR of the participants in the current study is similar to the 0.71 $L.h^{-1}$ SR reported in 12-13 year old males and females during 80 min cycling at 60% $\dot{V}O_{2max}$ in 33^{o}C heat (Bergeron *et al*., 2009). Comparing adolescent SR during exercise is difficult due to the influence of factors including exercise mode and intensity, environmental temperature and humidity, and biological maturation.

The similar between-trials SR and BM loss data in the current study may indicate similar systemic fluid availability, in line with previous work (Nicholas *et al*., 1995), and suggests that GE rate was not slowed in any trial to the extent where performance-attenuating thermoregulatory issues were encountered. It could therefore be inferred that the differences in intermittent endurance capacity in this study were not due to differences in GE rate of fluid and CHO, but rather to differences in the rate of intestinal absorption and subsequent oxidation of CHO_{exo}. However, neither GE rate nor CHO_{exo} oxidation was measured in this study, therefore future work should attempt to evaluate this. Furthermore, issues exist with inferring GE rate using measures of SR and BM loss due to potential errors associated with estimation of hydration from BM loss (Maughan *et al*., 2007) and the

potential for sub-conscious modification of effort to regulate fluid loss based on thirst perception during exercise (Edwards & Noakes, 2009).

5.4.6 Blinding

The blinding procedures in this study appeared successful (section 5.3.6). Furthermore, the data indicates that exercise did not provide any cues enabling participants to identify more accurately the three solutions (section 5.3.6). Interestingly, however, it does appear that some cues were provided to the participants during exercise that led them to believe falsely that they had not received the HCHO solution (section 5.3.6). It is impossible to speculate as to what these cues may have been, and whether they were perceived as positive or negative, without knowing what the individual participants' pre-exercise beliefs were regarding the HCHO solution. It should also be considered that asking participants to guess which dosage of CHO they received (i.e., 2, 6 or 10%) may be inherently more difficult than asking them to guess whether they received a treatment (i.e. CHO solution) or a control (i.e. PLA solution). The influence of prolonged intermittent, high-intensity exercise on adolescents' perceptions of CHO administration should be investigated further, considering the potential influence of an individual's perception of the treatment they believe they have received on their subsequent exercise performance (Beedie *et al*., 2007).

5.4.7 Preliminary tests

The mean V_{peak} from the incremental treadmill test in the current study is very similar to that reported in study 1 (section 4.3.1). The mean HR_{max} in the current study is again similar to study 1, and suggests that participants provided a maximal effort during the incremental test (Armstrong, 2007), which is reinforced by the mean RPE score and consistent observation of subjective markers of fatigue. The similar V_{peak}, HR and RPE data in the current study compared with study 1 indicates that the participants used in these two studies were of a similar training status, strengthening the comparisons made throughout this discussion.

5.5 Conclusion

Ingestion of a 6% CHO-E solution immediately before and during prolonged intermittent, high-intensity exercise significantly improves the intermittent endurance capacity of adolescent team games players compared with a 10% solution. A non-significant trend for greater intermittent endurance capacity was reported with ingestion of the 6% compared with the 2% solution, and the 2% compared with the 10% solution. Carbohydrate concentration did not significantly influence sprint performance or physiological responses during the exercise protocol. This study provides indirect evidence for the existence of low and high CHO ingestion thresholds in adolescents during prolonged intermittent, high-intensity exercise.

Chapter 6: The Influence of Ingesting a Carbohydrate Gel Immediately Before, and During, Prolonged Intermittent, High-Intensity Exercise on the Intermittent Endurance Capacity, Sprint Performance, and Physiological Response of Adolescent Team Games Players

Abstract

The aim of this study was to investigate the influence of ingesting a carbohydrate (CHO) gel on the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players. Eleven participants (ten males and one female; mean age 13.5 ± 0.7 years, height 171.9 ± 8.2 cm, body mass (BM) 62.1 ± 9.4 kg) performed two trials separated by 3–7 days. In each trial, they completed four 15 min periods of part A of the Loughborough Intermittent Shuttle Test (LIST), followed by an intermittent run to exhaustion (part B). In the 5 min pre-exercise, participants consumed 0.8 ml.kg^{-1} BM of a CHO or a non-CHO placebo (PLA) gel, and a further 0.3 ml.kg^{-1} BM every 15 min during part A of the LIST. Intermittent endurance capacity was increased by 21.1% during part B when the CHO gel was ingested (4.6 ± 2.0 vs. 3.8 ± 2.4 min, $P < 0.05$, $r = 0.67$), with distance covered in part B significantly greater in the CHO trial (787 ± 319 vs. 669 ± 424 m, $P < 0.05$, $r = 0.57$). Gel ingestion did not significantly influence mean 15 m sprint time ($P = 0.33$, r = 0.31), peak sprint time ($P = 0.81$, $r = 0.08$), or heart rate (HR; $P = 0.66$, $r = 0.16$). Ingestion of a CHO gel significantly increases the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

6.1 Introduction

The first two thesis studies demonstrated a significant enhancement in the intermittent endurance capacity of adolescent team games athletes with ingestion of a 6% CHO–E solution during a modified LIST. This was achieved with a mean CHO intake of ~35 g.h^{-1}, or ~0.78 g.kg^{-1} BM, which is notably lower than the CHO intake

in related adult work (Foskett *et al*., 2008; Nicholas *et al*., 1995; Welsh *et al*., 2002). Young people display a different metabolic response to exercise than adults, characterised by an enhanced rate of fat metabolism and attenuated rate of CHO_{endo} use (Riddell, 2008; Timmons *et al*., 2007[a]). Despite this, young people appear able to oxidise CHO_{exo} at BM-relative rates equal to, or greater than, adults (Timmons *et al*., 2003). Therefore, CHO_{exo} requirements of young people may be different to those of adults, perhaps with a lower rate of CHO ingestion facilitating exercise enhancement (section 5.4.1). This knowledge emphasises that findings from studies supplementing CHO during prolonged intermittent, high-intensity exercise in adults cannot be confidently applied to young people, and greater research into CHO supplementation during prolonged intermittent, high-intensity exercise in adolescents is therefore warranted.

In recent years, ingestion of CHO in the form of a gel has become more prevalent (Havemann & Goedecke, 2008), due in part to the ability to manipulate CHO and fluid intake independently, and to consume greater amounts of CHO in gel compared with solution form (Pfeiffer *et al*., 2010). Carbohydrate gel ingestion has been shown to improve prolonged steady-state cycling performance (Campbell *et al*., 2008; Earnest *et al*., 2004), with a negligible effect on half-marathon running performance (Burke *et al*., 2005). However, in this latter study the ~2.4% BM loss during the run, along with the presence of an order effect for performance time, may have negated the effect of the gel. Specific to prolonged intermittent, high-intensity exercise, Patterson and Gray (2007) showed a 45% improvement in intermittent endurance capacity when adult male soccer players ingested a CHO gel before and during the LIST. This is comparable to the improvement seen when consuming CHO–E solutions during a similar protocol (~33–52%, Foskett *et al*., 2008; Nicholas *et al*., 1995; Welsh *et al*., 2002). To date, this remains the only study to investigate CHO gel supplementation during prolonged intermittent, high-intensity exercise. Unfortunately, the use of a PLA solution as opposed to a gel exposes the Patterson and Gray (2007) study to potential blinding concerns, which poses a problem when trying to *interpret* the data with confidence.

The potential of CHO gels as a flexible alternative method of CHO ingestion compared to CHO solutions is valuable to athletes, but has to date been under-researched. This is particularly true for prolonged intermittent, high-intensity exercise, where the only available study contains a crucial methodological limitation. Further study into CHO gel ingestion during prolonged intermittent, high-intensity exercise should attempt to elucidate whether CHO gel ingestion is a feasible alternative to ingestion of CHO solutions.

Research Question: Does ingestion of a carbohydrate gel immediately before and during prolonged intermittent, high-intensity exercise influence the intermittent endurance capacity, sprint performance, and physiological response of adolescent team games players?

Hypothesis 1: Ingesting a carbohydrate gel will significantly increase the intermittent endurance capacity of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 2: Ingesting a carbohydrate gel will not significantly influence the repeated 15 m sprint performance of adolescent team games players during prolonged intermittent, high-intensity exercise.

Hypothesis 3: Ingesting a carbohydrate gel will not significantly influence the physiological response, as measured by HR, SR and BM loss, of adolescent team games players during prolonged intermittent, high-intensity exercise.

6.2 Methods

In addition to the general methods chapter (chapter 3), this section describes the exact protocols used, as well as any procedures or measurements exclusive to this study.

6.2.1 Participants

Eleven team games players (10 males and 1 female) participated in the study. Physical and biological characteristics are in table 6.1.

Table 6.1 Physical and biological characteristics of participants. Data are mean ± SD (range).

	Age (years)	**Height (cm)**	**Body Mass (kg)**	**Maturity Offset (years)**
All participants (n = 11)	13.5 ± 0.7 (12-14)	171.9 ± 8.2 (148.3-179.2)	62.1 ± 9.4 (42.8-73.9)	+0.94 (-1.77-+2.68)

6.2.2 Preliminary tests

6.2.2.1 Peak running velocity

On their first visit to the laboratory, participants performed a treadmill familiarisation and V_{peak} test followed by a familiarisation of the LIST protocol, as described in section 3.2.1.

6.2.3 Experimental design

Participants' completed two trials, consuming either a 100% maltodextrin CHO gel (CHO trial; High5 Ltd, Bardon, UK) or a non-CHO artificially sweetened gel (PLA trial; High5 Ltd, Bardon, UK), matched for taste, texture, and mouth feel. Gel compositions were as follows:

Carbohydrate gel

The following composition information refers to one 60 ml sachet of gel. The CHO gel was composed of a long-chain glucose polymer yielding 22 g of CHO (37% concentration). Low-calorie fruit juices (Apple, Raspberry, Strawberry, and

Cranberry) at 10% of total gel volume were included for flavouring. Total electrolyte composition of the gel was: Na^+, 30 mg; K^+, 140 mg.

Placebo gel

The following composition information refers to one 60 ml sachet of gel. The PLA gel was composed of low-calorie fruit juices (Apple, Raspberry, Strawberry, and Cranberry) at 10% of total gel volume, along with artificial sweeteners (Aspartame and Acesulfame K). Total electrolyte composition of the gel was: Na^+, 30 mg; K^+, 140 mg.

Pilot work confirmed that the gels were blinded well for taste, texture, and mouth-feel. The gels were consumed in amounts that enabled a standardised CHO intake of 0.78 $g.kg^{-1}$ BM for each participant, or a mean of 38.0 $g.h^{-1}$ for all participants, to enable a direct comparison with study 1 (chapter 4). As the two gels were slightly different colours they were prepared in non-transparent bottles by the individual in control of trial blinding, so that neither the investigator nor the participants could see the gel at any time.

6.2.4 Experimental protocol

Participants arrived at the laboratory in a fed, post-prandial state. For logistical reasons, it was not possible to test all participants at the same time of day, but within-participants sessions were completed at the same time of day or as near as possible. Sessions began between 10am and 6pm. During each trial, participants performed the LIST protocol as detailed in section 3.2.2 and figure 3.4. Participants consumed the pre-exercise bolus of the prescribed solution (0.8 $ml.kg^{-1}$ BM gel followed by 5 $ml.kg^{-1}$ BM water) and the boluses during exercise (0.3 $ml.kg^{-1}$ BM gel followed by 2 $ml.kg^{-1}$ BM water) as described in section 4.2.4. Water was ingested to offset the potential influence of dehydration (Patterson & Gray, 2007), and was consumed in the same volumes as the CHO-E solutions used in the previous thesis studies (section

4.2.4 & 5.2.4). Participants were asked to state which gel they believed was being prescribed as detailed in section 5.2.4.

6.2.5 Measurements

All measurements made during the study are detailed in section 3.3.

6.2.6 Statistical analysis

The following statistical analyses were completed, in addition to that detailed in section 3.4. Paired *t*-tests compared between-trials differences in fluid, gel and CHO intake, pre-exercise BM, BM loss and SR, HR during part B, and HR, GF and GD at exhaustion. Distance covered in part A and B, and time to exhaustion and RPE at exhaustion in part B were analysed using the Wilcoxon matched-pairs test. Mean ambient temperature and relative humidity, mean sprint times and mean peak sprint times, HR, GF and GD during part A were analysed with a 2 way (gel x time) ANOVA. Bonferroni pairwise comparisons were used to explore significant main effects with the exception of GF, where Wilcoxon matched-pairs tests with Bonferroni correction were used due to the grouped data displaying non-normal distribution. Wilcoxon matched-pairs tests with Bonferroni correction analysed between-trials differences in RPE during part A, with Friedman tests analysing the main effect of time during part A within each trial. Wilcoxon matched-pairs tests, with Bonferroni correction, explored significant within-trials main effects. Chi-square analysis assessed the frequency distribution of gel choice responses. Unless specified, data are mean ± SD.

6.3 Results

An insufficient number of females were recruited to perform between-gender statistical analyses, therefore the data was treated as a single cohort. The data was analysed with and without the female participant included, and it was confirmed that the significance of the data was not affected by inclusion of the female data.

6.3.1 Preliminary tests

Mean V_{peak} attained in the incremental treadmill run to exhaustion was 14.6 ± 0.9 $km.h^{-1}$. Mean HR_{max} and RPE at exhaustion were 197 ± 6 beats per min and 9.2 ± 0.4, respectively.

6.3.2 Distance covered and time to exhaustion

By design, distance covered during part A was the same in the CHO and PLA trials (7.1 ± 0.2 km). Time to exhaustion during part B of the LIST for both trials is shown in figure 6.1, with time to exhaustion for each individual participant in both trials shown in figure 6.2. Participants ran for 21.1% longer time in the CHO compared to the PLA trial ($P < 0.05$, $r = 0.67$), with distance covered in part B also significantly greater in the CHO trial (787 ± 319 vs. 669 ± 424 m, $P < 0.05$, $r = 0.57$). One participant elicited a 15.8% improvement in intermittent endurance capacity in the PLA trial compared to the CHO trial. This is in contrast to all other participants in the study including the one other participant who ran longer in the PLA trial (between-trials difference of 0.3%).

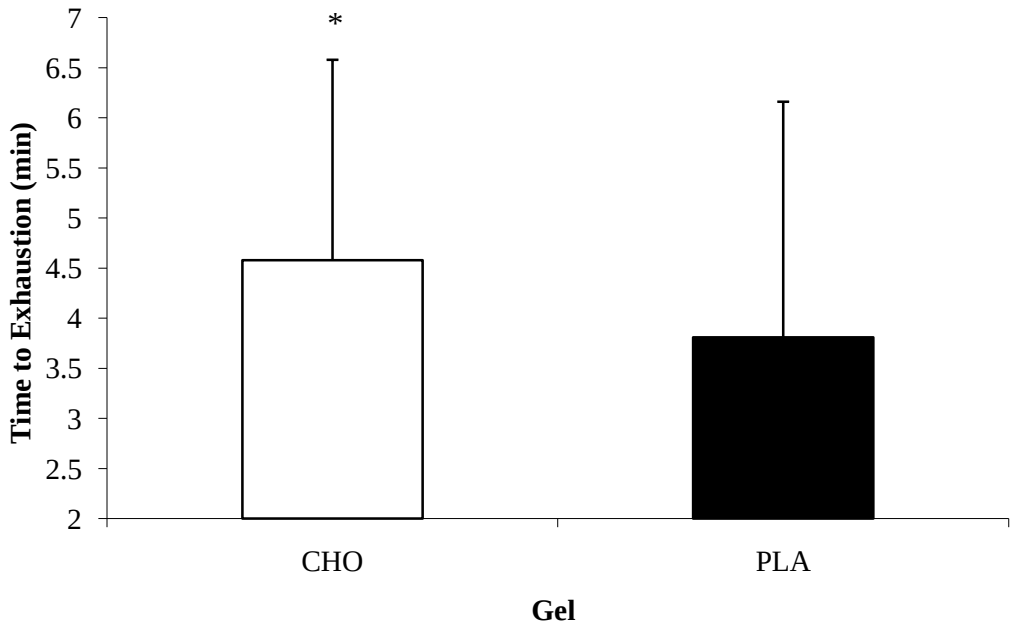

Figure 6.1 Time to exhaustion (min) during part B of the Loughborough Intermittent Shuttle Test for both trials. * significantly greater than the PLA trial, $P < 0.05$. Data are mean ± SD ($n = 11$).

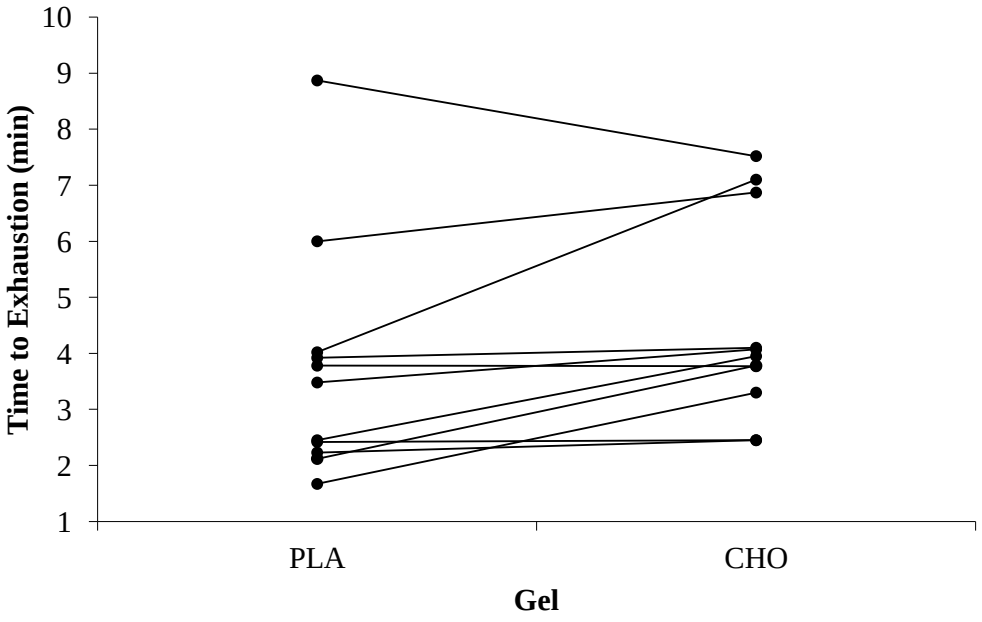

Figure 6.2 Time to exhaustion (min) during part B of the Loughborough Intermittent Shuttle Test for each participant in both trials ($n = 11$).

6.3.3 Sprint times

The mean time of all sprints, and the mean of participants' peak sprint time only, completed in each block of part A of the LIST are shown in figure 6.3A and 6.3B, respectively. A trend for faster mean sprint times in the CHO trial was found, but did not reach statistical significance ($F_{1, 10} = 1.1$, $P = 0.33$, $r = 0.31$). There was also no interaction effect (gel x time, $F_{3, 30} = 0.4$, $P = 0.75$, $r = 0.20$). There was a main effect of time on sprint duration ($F_{3, 30} = 25.1$, $P < 0.001$, $r = 0.85$). Sprint times in block 2 were significantly slower than block 1 ($P < 0.05$, $r = 0.77$) and in block 3 were significantly slower than block 2 ($P < 0.05$, $r = 0.80$). There was no significant difference in sprint time between blocks 3 and 4 ($P = 0.21$, $r = 0.68$). There was no significant between-trials difference ($F_{1, 10} = 0.06$, $P = 0.81$, $r = 0.08$) or interaction effect ($F_{3, 30} = 0.4$, $P = 0.72$, $r = 0.21$) for peak sprint time. There was a main effect of time on peak sprint duration ($F_{3, 30} = 15.1$, $P < 0.001$, $r = 0.78$). Sprint times in block 3 were significantly slower than block 2 ($P < 0.05$, $r = 0.82$). There was no significant difference between blocks 1 and 2 ($P = 0.33$, $r = 0.52$) or 3 and 4 ($P = 1.0$, $r = 0.41$).

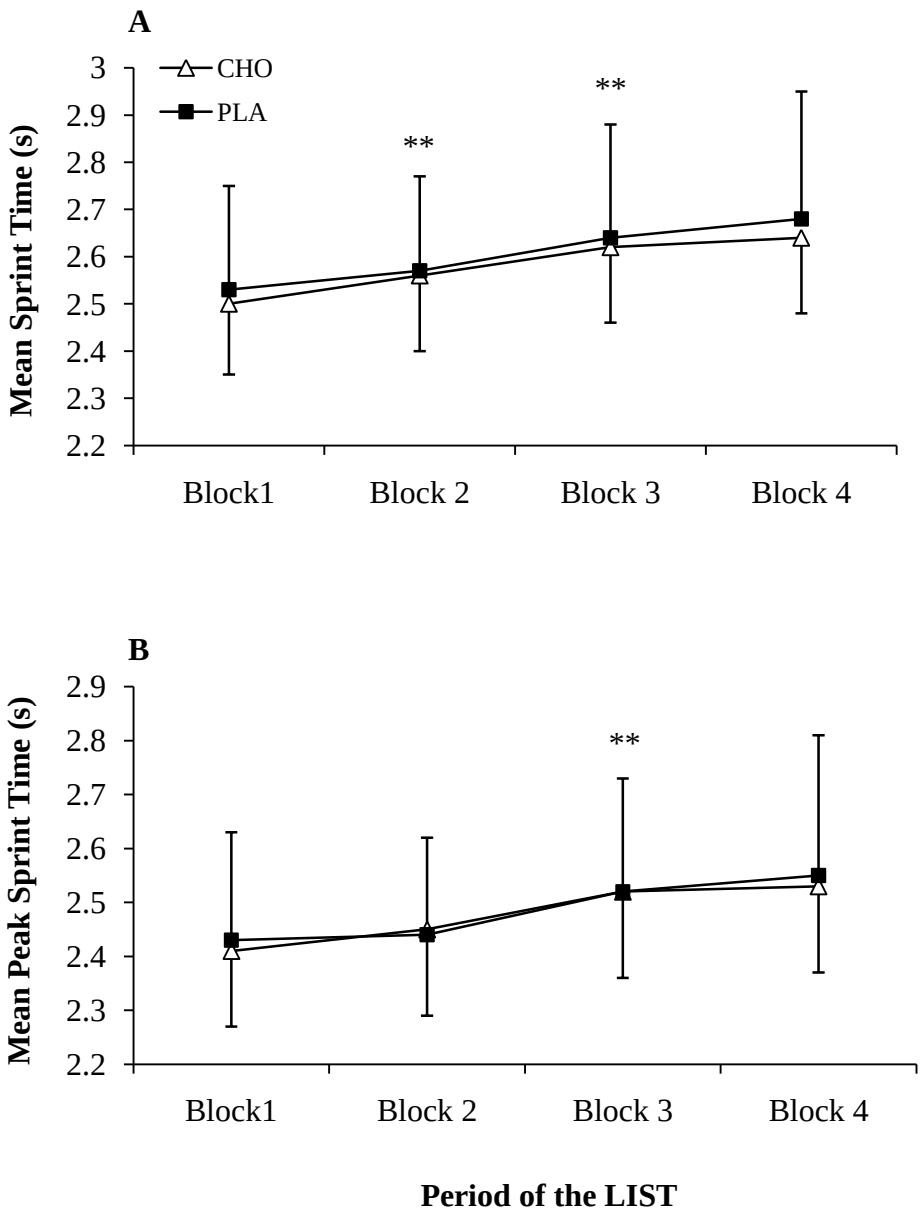

Figure 6.3 Mean sprint time (s, A) and mean peak sprint time (s, B) during part A of the Loughborough Intermittent Shuttle Test for both trials. Data are mean ± SD (n = 11). ** significantly greater than previous block, $P < 0.05$.

6.3.4 Heart rate, ratings of perceived exertion and gastric disturbances

Mean HR and RPE during part A of the LIST, and mean peak HR and mean RPE at exhaustion in part B are shown in table 6.2. There was no significant treatment ($F_{1, 8}$ = 0.21, P = 0.66, r = 0.16) or interaction ($F_{3, 24}$ = 1.34, P = 0.29, r = 0.38) effect on

HR during part A of the LIST. There was a main effect of time for HR in part A ($F_{1.3, 10.6} = 12.18$, $P < 0.005$, $r = 0.78$). Heart rate in block 2 was significantly greater than block 1 ($P < 0.001$, $r = 0.95$). There was no significant difference between blocks 2 and 3 ($P = 1.0$, $r = 0.14$) or 3 and 4 ($P = 0.97$, $r = 0.35$). Mean HR during part B of the LIST was greater in the CHO trial, but did not reach statistical significance (175 ± 5 vs. 173 ± 6 beats per min, $P = 0.42$, $r = 0.31$). Peak HR at exhaustion in part B was also higher in the CHO trial, but again this was not significant ($P = 0.56$, $r = 0.23$). Mean RPE was very similar at all time points between trials, with no significant differences found. A main effect of time was present for the CHO ($\chi^2(3) = 29.8$, $P < 0.001$) and PLA ($\chi^2(3) = 31.1$, $P < 0.001$) trials. Ratings of perceived exertion increased significantly with each successive exercise block ($P < 0.001$, $r = 0.89$, 0.76 and 0.76, respectively). There was no between-trials difference in RPE at exhaustion ($P = 1.0$, $r = 0$).

Mean GF and GD during part A of the LIST, and at exhaustion in part B, are shown in table 6.3. There was a trend for mean GF to be greater in the CHO trial throughout part A of the LIST, but this was not statistically significant ($F_{1, 10} = 3.50$, $P = 0.09$, $r = 0.51$). There was also no interaction effect ($F_{1.7, 17.4} = 0.65$, $P = 0.52$, $r = 0.25$). There was a significant effect of time on GF ($F_{1.5, 14.7} = 7.72$, $P < 0.01$, $r = 0.66$). Gut fullness in block 3 was significantly greater than block 2 ($P < 0.01$, $r = 0.56$). There was no significant difference between blocks 1 and 2 ($P = 0.06$, $r = 0.40$) or 3 and 4 ($P = 1.0$, $r = 0$). Gut fullness scores during part A of the LIST were modest. There was a trend for GF at exhaustion to be higher in the CHO trial, but this was not statistically significant ($P = 0.24$, $r = 0.37$). There was no treatment ($F_{1, 10} = 0.14$, $P = 0.72$, $r = 0.11$) or interaction ($F_{3, 30} = 0.97$, $P = 0.42$, $r = 0.30$) effect on GD. Gastric discomfort increased significantly with time ($F_{1.5, 14.5} = 13.06$, $P < 0.005$, $r = 0.75$), and was significantly greater in block 2 than block 1 ($P < 0.05$, $r = 0.64$) and block 3 than block 2 ($P < 0.05$, $r = 0.54$). There was no significant difference between blocks 3 and 4 ($P = 1.0$, $r = 0.06$). Gastric discomfort scores during part A were also moderate. There was a trend for GD at exhaustion to be higher in the CHO trial, but this was not statistically significant ($P = 0.59$, $r = 0.17$).

Table 6.2 Mean heart rate (beats per min) and mean ratings of perceived exertion during part A of the Loughborough Intermittent Shuttle Test, and mean peak heart rate and mean ratings of perceived exertion at exhaustion in part B for both trials. Data are mean ± SD (n = 11).

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean heart rate (beats per min)					
CHO	158 ± 7	163 ± 7***	164 ± 7	163 ± 6	187 ± 5
PLA	158 ± 9	162 ± 10***	163 ± 9	162 ± 9	185 ± 5
Mean ratings of perceived exertion					
CHO	5.1 ± 1.4	6.4 ± 1.1***	7.2 ± 0.6***	8.1 ± 0.5***	9.4 ± 0.5
PLA	5.0 ± 1.1	6.3 ± 0.9***	7.3 ± 1.0***	8.2 ± 0.8***	9.4 ± 0.5

CHO = carbohydrate trial; PLA = placebo trial

*** significantly greater than previous block, $P < 0.001$

Table 6.3 Mean gut fullness and gastric discomfort ratings during part A of the Loughborough Intermittent Shuttle Test, and at exhaustion in part B, for both trials. Data are mean ± SD (n = 11).

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean gut fullness ratings					
CHO	4.3 ± 1.9	4.4 ± 1.9	5.2 ± 1.6†	5.2 ± 1.8	5.3 ± 1.8
PLA	3.4 ± 1.3	4.0 ± 1.1	4.5 ± 1.4†	4.5 ± 1.5	4.7 ± 1.3
Mean gastric discomfort ratings					
CHO	3.0 ± 1.7	3.5 ± 2.0**	4.5 ± 2.0**	4.5 ± 2.3	5.5 ± 2.3
PLA	2.8 ± 1.6	3.9 ± 1.9**	4.3 ± 2.5**	4.3 ± 2.3	5.3 ± 2.0

CHO = carbohydrate trial; PLA = placebo trial

† significantly greater than previous block, $P < 0.01$; ** significantly greater than previous block, $P < 0.05$.

6.3.5 Body mass loss and sweat rate

Mean pre-exercise dry nude BM was not significantly different between the CHO and PLA trials (62.4 ± 9.1 and 62.9 ± 9.2 kg, respectively, $P = 0.27$, $r = 0.34$). Mean BM loss in the CHO and PLA trials was 1.0 ± 0.4 and 1.1 ± 0.3 kg, respectively ($P = 0.36$, $r = 0.29$), equating to a mean loss of 1.59 ± 0.53 and 1.67 ± 0.37% of pre-exercise BM ($P = 0.50$, $r = 0.22$). Mean SR was 0.77 ± 0.27 and 0.85 ± 0.27 $L.h^{-1}$ in the CHO and PLA trials, respectively ($P = 0.30$, $r = 0.33$), equating to a BM-relative mean sweat loss of 12.42 ± 4.16 and 13.44 ± 3.70 $ml.kg^{-1}.h^{-1}$, respectively ($P = 0.39$, $r = 0.28$).

6.3.6 Blinding

The number of participants who gave correct and incorrect solution choices pre- and post-exercise for each trial is shown in figure 6.3. After consuming the initial bolus of gel immediately prior to exercise, four participants (36%) correctly identified both gels and seven (64%) failed to do so. Chi square analysis of the pre-exercise responses in the CHO trial found a non-significant deviation from the expected response frequency ($\chi^2(1) = 0.818$, $P = 0.37$). In the PLA trial, five participants (46%) correctly guessed the PLA gel post-exercise when they had incorrectly guessed prior to exercise. Two participants (18%) incorrectly chose the CHO gel post-exercise when they had correctly guessed prior to exercise. In the CHO trial, five participants (46%) incorrectly chose the PLA gel post-exercise when they had correctly guessed pre-exercise. No participants correctly guessed the CHO gel post-exercise after having guessed incorrectly pre-exercise. Post-exercise, only two participants correctly guessed both gels. These participants also guessed both gels correctly pre-exercise.

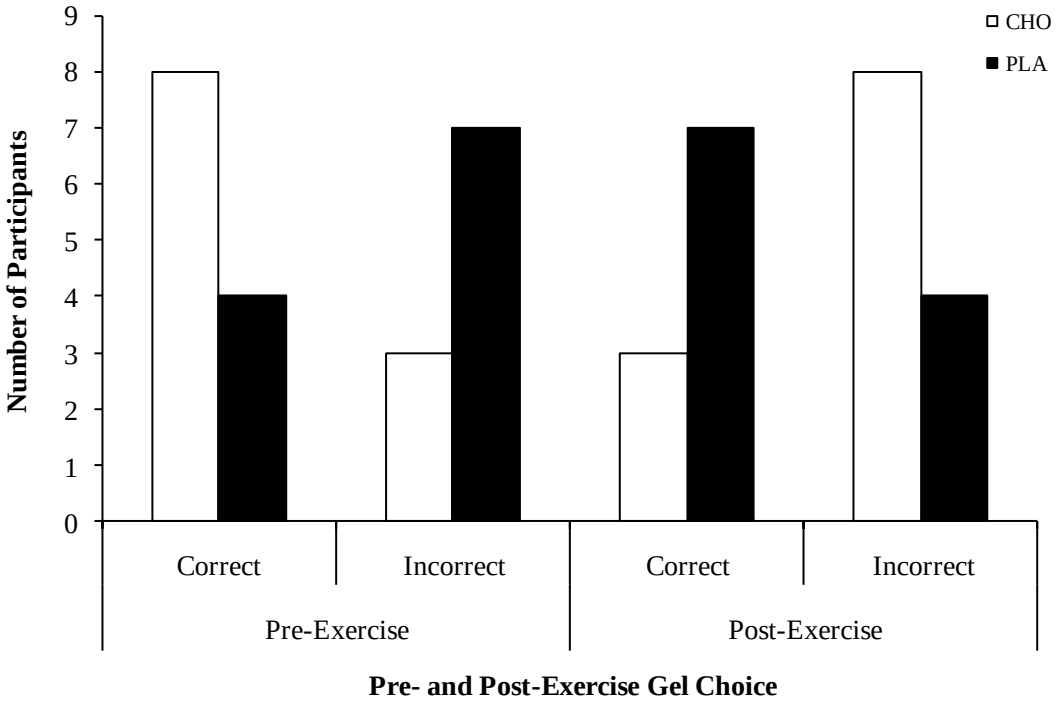

Figure 6.4 Number of participants who made correct and incorrect solution choices, pre- and post-exercise, for each trial.

6.3.7 Fluid and carbohydrate intake

Mean fluid intake was 811 ± 119 and 811 ± 120 ml for the CHO and PLA trials, respectively (P = 0.93, r = 0.03). Mean gel intake in the CHO trial was 132.6 ± 19.4 ml and in the PLA trial was 132.7 ± 19.6 ml (P = 0.92, r = 0.03). Combined fluid and gel intake was 943.6 ± 138.3 and 943.9 ± 139.4 ml (P = 0.92, r = 0.03) in the CHO and PLA trials, respectively. In the CHO trial, total CHO intake was 38.0 ± 5.5 $g.h^{-1}$, equating to 0.78 $g.kg^{-1}$ BM.

6.3.8 Ambient temperature and relative humidity

Mean ambient temperature and relative humidity during the LIST are shown in table 6.4. Mean ambient temperature was not influenced by solution ($F_{1, 10}$ = 3.58, P = 0.09, r = 0.51) or time ($F_{1.1, 10.6}$ = 0.06, P = 0.60, r = 0.18), but an interaction effect was present ($F_{1.7, 16.7}$ = 3.87, $P < 0.05$, r = 0.53). Mean relative humidity was not significantly different between $F_{1, 10}$ = 4.90, P = 0.051, r = 0.57) or within ($F_{1.9, 18.9}$ = 1.38, P = 0.28, r = 0.35) trials, and there was no interaction effect ($F_{1.7, 17.4}$ = 1.08, P = 0.35, r = 0.31).

Table 6.4 Mean ambient temperature (^{o}C) and relative humidity (%) immediately before, and during, part A of the Loughborough Intermittent Shuttle Test for both trials. Data are mean ± SD (n = 11).

	Period of the LIST				
	Pre-exercise	Block 1	Block 2	Block 3	Block 4
Mean ambient temperature (^{o}C)					
CHO	18.5 ± 1.2	18.5 ± 1.2	18.5 ± 1.3	18.5 ± 1.3	18.5 ± 1.3
PLA	18.8 ± 1.1	18.9 ± 1.1	18.9 ± 1.1	18.9 ± 1.1	18.9 ± 1.1
Mean relative humidity (%)					
CHO	39.5 ± 8.0	39.5 ± 8.1	39.4 ± 8.2	39.5 ± 8.6	39.2 ± 8.5
PLA	45.6 ± 7.5	44.8 ± 7.3	44.7 ± 7.1	44.6 ± 7.3	44.6 ± 7.3

CHO = carbohydrate trial; PLA = placebo trial

A significant interaction effect (gel x time) was reported for mean ambient temperature, $P < 0.05$.

6.4 Discussion

This study demonstrates that ingestion of a CHO gel immediately before, and during, prolonged intermittent, high-intensity exercise significantly increases the intermittent endurance capacity of adolescent team games players. Carbohydrate gel supplementation did not exert a significant influence on the repeated sprint performance or physiological response of adolescent team games players during the exercise protocol.

6.4.1 Time to exhaustion

The improvement in time to exhaustion in the current study is similar to the 24.4% improvement reported in study 1 from ingestion of a 6% CHO-E solution before and

during the same exercise protocol (chapter 4). Therefore, the current study serves to increase the knowledge base and provide further evidence for an ergogenic effect of CHO supplementation during prolonged intermittent, high-intensity exercise in adolescent team games players. Furthermore, it appears that CHO gels and solutions of similar composition, when administered in volumes that deliver an equal amount of BM-relative CHO, have similar efficacies for adolescents during prolonged intermittent, high-intensity exercise. The observation of a similar time-course of CHO oxidation and peak CHO oxidation rate between CHO gels and drinks of the same composition (Pfeiffer *et al*., 2010) may help to explain this, but would need to be confirmed in adolescents.

The findings in the present study are consistent with those of Patterson and Gray (2007). These authors reported a significant elevation in blood glucose levels in the CHO trial throughout exercise, along with no significant between-trials differences in HR, RPE or BM loss, leading to the conclusion that increased intermittent endurance capacity was due to CHO-mediated sparing of muscle glycogen during exercise. This is the mechanism commonly cited to explain increased time to exhaustion with ingestion of CHO-E solutions during prolonged intermittent, high-intensity exercise. However, it is not universally accepted (Coyle *et al*., 1986). Evidence for a beneficial effect of CHO mouth washes on exercise performance lasting ~1 h (Carter *et al*., 2004; Rollo *et al*., 2008) and the suggestions of Chambers *et al*. (2009) that CHO detection in the oral cavity may activate reward and motor control centres of the brain provides an alternative hypothesis for the efficacy of CHO gel ingestion. However, the presence of this mechanism in the Patterson and Gray (2007) study cannot be quantified. The current study did not collect data that may have enabled direct quantification of enhancement mechanisms. However, the lack of significant between-trials differences in any measured variables, along with the knowledge that muscle and hepatic glycogen concentrations are lower in early adolescence compared to adulthood (Aucouturier *et al*., 2008) and that PP children and, possibly, adolescents, are able to oxidise a greater relative amount of CHO_{exo} than adults (Timmons *et al*., 2003), suggests that sparing of muscle glycogen during exercise may be an enhancement mechanism in this population (section 4.4.1). It would be

valuable for future work to collect metabolic data that could elucidate this hypothesis. As with the study of Patterson and Gray (2007), the presence of a perceptual influence of CHO ingestion in the current study cannot be confidently confirmed or refuted with the measurements made.

The improvement in intermittent endurance capacity in the current study is notably lower than the 45% improvement reported by Patterson and Gray (2007), which follows the trend between improvements in intermittent endurance capacity with ingestion of a 6% CHO-E solution in adolescents and adults (section 4.4.1). A single study, regardless of its degree of scientific rigour, does not represent a sufficient weight of research. Therefore, both the current study and that of Patterson and Gray (2007) should be repeated, which will provide a reference range of enhancement figures similar to those for research using CHO solutions (section 5.4.1). This may enable a clearer picture of the relative intermittent endurance capacity enhancement of adolescents and adults with CHO gel ingestion. However, it could be hypothesised that greater fat oxidation in young people during exercise may reduce the influence of CHO ingestion, perhaps attenuating the ergogenic response compared with adults (section 4.4.1). This cannot be confirmed without collecting metabolic measurements during exercise. Importantly, the use of a PLA solution, rather than a gel, by Patterson and Gray (2007) could have influenced the results, and may help to explain the difference in time to exhaustion improvement compared with the current study. However, it is important to reiterate that participants in this study exercised in a fed, post-prandial state. The potential influence of pre-exercise nutritional status on substrate use, exercise performance, and the efficacy of CHO ingested during exercise (Burke *et al*., 1998; Chryssanthopoulos & Williams, 1997; Coyle *et al*., 1985; Neufer *et al*., 1987) should be considered, as this may have played a role in the lower intermittent endurance capacity reported in the current study compared with that of Patterson and Gray (2007).

In the current study, one participant elicited a large improvement in intermittent endurance capacity in the PLA trial compared to the CHO trial, in comparison to all other participants in the study. The participant in question also took part in study 2

of this thesis (chapter 5). When the data from study 2 was investigated it became apparent that the differences in the participant's time to exhaustion data, while following the trend of results observed in the other participants, was considerably lower than the sample mean differences. Data on the non-response to CHO supplementation in healthy exercising humans is not available. Medical conditions may cause alterations or irregularities in CHO metabolism (Grassi *et al*., 2009), but it is clearly inappropriate to speculate in this area. Maturational status may be a possible explanatory factor; however, the maturity offset of the participant in question was similar to a number of other participants in the study who displayed notable improvements in time to exhaustion with CHO gel ingestion. Dietary intake prior to both trials was standardised, excluding this as a possible explanation. Participants' health status was not medically quantified prior to the trials, but before each trial they were asked whether they felt fit and well enough to complete the trial to the best of their ability. While participants' pre-exercise dietary status was standardised between-trials, the pre-exercise diet of the participant in question may have been notably different to other participants in the study. Therefore, this is a potential explanation for the finding.

6.4.2 Sprint performance

The finding that CHO gel supplementation did not significantly improve mean sprint or mean peak sprint performance during the protocol is consistent with the other two studies in this thesis (chapters 4 & 5), as well as previous adult work (Patterson & Gray, 2007). Possible reasons for the lack of influence of CHO supplementation on sprint performance have been discussed previously (section 4.4.2). The similar metabolic response with ingestion of a CHO gel suggests (Pfeiffer *et al*., 2010) that these reasons may also explain the lack of significant influence of CHO gel ingestion on sprint performance. Therefore, this study further reinforces that CHO ingestion does not significantly improve the sprinting ability of adolescents during prolonged intermittent, high-intensity exercise.

The mean increase in sprint time from the first to the last block of part A in the current study agrees with data from the previous two studies (sections 4.4.2 & 5.4.2) further indicating that young participants do not display a greater fatigue resistance than adults during sprinting in the LIST. The increase in sprint time from blocks 1-4 in both trials of the current study is smaller than that reported in study 1 (section 4.4.2) but similar to study 2 (section 5.4.2), again demonstrating that sprint performance in adolescents during team games exercise is variable. The large ES for the differences in sprint time between each successive block in the current study suggests that the attenuation of sprint performance is of practical, if not statistical, significance.

Interestingly, the only significant attenuation in peak sprint time in the current study occurred between blocks 3 and 4, which also corresponded with a significant increase in both GF and GD measures (section 6.4.5). It may be that this increase in GF and GD inhibited sprint performance, and is further supported by the significant attenuation of mean sprint time over the same period. However, in study 2 peak sprint performance was significantly attenuated in block 3 only (section 5.3.3), without a corresponding significant increase in GF or GD (section 5.3.4 & table 5.3). Furthermore, in the current study moderate to large ES were reported for the differences in peak sprint time between each successive block (section 6.3.3). Therefore, the parallel increases in these measures in the current study may be coincidental. More research will enable a clearer picture of the sprint performance of adolescents during team games exercise.

6.4.3 Heart rate and ratings of perceived exertion

The similar between-trials HR response during part A of the LIST in the current study agrees with previous studies in this thesis (sections 4.3.4 & 5.3.4) and most adult work (Ali *et al*., 2007; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Welsh *et al*., 2002). Furthermore, the significant increase in HR from block 1 to 2 of the LIST in the current study, with no other significant difference, agrees with the previous thesis studies (sections 4.3.4 & 5.3.4). The non-significant trend for a higher HR in the

CHO trial has been reported in adult (Ali *et al*., 2007; Foskett *et al*., 2008) and adolescent work (section 4.3.4), and may be explained by non-significantly faster mean sprint times in the CHO trial (section 4.4.3).

In study 1 of this thesis, a significantly greater peak HR at exhaustion in the CHO trial was reported (section 4.3.4), something that had not been found previously. This finding was not replicated in study 2 (section 5.3.4) or the current study. It is difficult to suggest reasons behind these different findings, but the absence of a significantly higher peak HR at exhaustion in studies 2 and 3 reinforces the hypothesis that the finding of study 1 may have been an artefact of the specific participant population used (section 5.4.3). More work in this area will enable clarification of the HR response of adolescents at exhaustion during high-intensity, intermittent running.

The progressive increase in RPE with time, irrespective of treatment, in the current study again replicates findings from prior studies (section 4.3.4 & 5.3.4) and adult work (Ali *et al*., 2007; Nicholas *et al*., 1995; Nicholas *et al*., 1999; Welsh *et al*., 2002). The lack of a between-trials difference during part A of the LIST in the current, and previous, studies (section 4.3.4 & 5.3.4), reinforces the notion that CHO supplementation during team games exercise does not elicit centrally-mediated alterations that alter the effort perception of adolescents during exercise (Ali *et al*., 2007; Welsh *et al*., 2002), indicating metabolic mechanisms behind improvements in intermittent endurance capacity in these participants.

6.4.4 Carbohydrate and fluid intake

Mean CHO intake in the current study was purposely matched with study 1 (chapter 4) to enable a direct comparison between CHO solution and gel ingestion during the same exercise protocol in a similar group of adolescent team games athletes. Clearly, the BM-relative and absolute CHO intake in this study and study 1 is lower than adult research, for reasons previously discussed (section 4.4.4). It is also lower than that recommended by adult guidelines for performance enhancement. However,

a significant ergogenic effect was still reported. The results of studies 1 and 3 reinforce the findings of study 2 that ingestion of ~0.78 $g.kg^{-1}$ BM CHO enhances intermittent endurance capacity during prolonged intermittent, high-intensity exercise in adolescents, and suggest that young people require less CHO_{exo} than adults to elicit an ergogenic effect during this form of exercise.

6.4.5 Gut fullness and gastric discomfort

The time effects on GF and GD in the current study, along with the lack of a treatment or interaction effect, either partially (section 4.3.4) or fully (section 5.3.4) agree with previous studies. The lack of a treatment effect on GF or GD indicates that a CHO gel is tolerated as well as an isoenergetic CHO-E solution by adolescents during prolonged intermittent, high-intensity exercise (section 4.4.5). This is in agreement with Patterson and Gray (2007), who reported no significant treatment effects for gastric disturbances with CHO gel ingestion during prolonged intermittent, high-intensity exercise in adults. The greater concentration of gels means that a lower volume is ingested to achieve a given CHO intake compared with a solution, which may explain the good tolerance of gels (Noakes *et al*., 1991). Interestingly, a large ES was reported for the main effect of treatment on GF, indicating a possible practical influence of CHO gel ingestion on GF. However, as with previous studies in this thesis (section 4.3.4 & 5.3.4), only moderate sensations of GF and GD were reported in the current study. Possible reasons behind the treatment-independent increase in GF and GD with time have been discussed previously (section 4.4.4).

6.4.6 Body mass loss and sweat rate

The non-significant between-trials difference in BM loss in the current study is in agreement with studies 1 and 2 (sections 4.3.5 & 5.3.5) and previous adult work (Ali *et al*., 2007; Nicholas *et al*., 1995; Nicholas *et al*., 1999). The similar between-trials mean SR in the current study is also in line with the other studies in this thesis (sections 4.3.5 & 5.3.5). Once again, percentage BM loss and SR ($L.h^{-1}$ and $ml.kg^{-1}$

$BM.h^{-1}$) in the current study was very similar to studies 1 and 2 (sections 4.3.5 & 5.3.5). Together, this data suggests a lack of influence of CHO, in different amounts and mediums, on the BM loss and SR responses of adolescents to prolonged intermittent, high-intensity exercise. Comparison of SR data with adult work is irrelevant as young people's SR is lower than adults' (section 2.1.3.1), and the similar percentage BM losses between adolescents and adults during prolonged intermittent, high-intensity exercise have been highlighted elsewhere (section 4.4.6). These data represent the only published information currently available on the BM loss and SR of adolescents during prolonged intermittent, high-intensity exercise, therefore further comparative discussion is not possible.

6.4.7 Blinding

Exercise did not appear to provide any cues enabling participants to identify more accurately which gel they were consuming. However, analysis of the individual trials suggests that exercise did enable participants to recognise the PLA gel more easily (figure 6.3). The apparent inability of the participants to recognise the CHO gel post-exercise may further indicate that CHO does not exert a perceptual influence on young people during prolonged intermittent, high-intensity exercise, but this requires further study. Despite this, as both correct and incorrect changes in gel selection post-exercise were present it would be interesting to further investigate the influence of team games exercise on adolescents' perception of CHO gel and solution administration, for reasons previously highlighted (section 5.4.6). Formulation of perceptions regarding gel administrations by participants cannot be prevented, and can only be controlled by employing stringent blinding procedures that will adequately randomise these perceptions and minimise their influence.

6.4.8 Preliminary tests

The mean V_{peak} attained in the incremental treadmill test in the current study is the same as that reported in study 1 (section 4.3.1) and very similar to that reported in study 2 (section 5.3.1). The mean HR_{max} and RPE values recorded in the current

study, coupled with consistent observation of subjective markers of fatigue, provides strong evidence that a maximal effort was generated by the participants (section 4.4.8). These values also correspond well with those from study 1 (section 4.3.1) and 2 (section 5.3.1) and, along with the V_{peak} data, partially validate the comparisons made between these three studies throughout this discussion.

6.5 Conclusion

Ingestion of a CHO gel immediately before, and during, prolonged intermittent, high-intensity exercise significantly improves the intermittent endurance capacity of 12-14 year old team games players. Carbohydrate gel ingestion had no significant influence on sprint performance or physiological responses to prolonged intermittent, high-intensity exercise in these participants.

Chapter 7: General Discussion and Conclusions

Chapter Aims

This chapter provides a cohesive summary and discussion of the research findings presented in chapters 4-6. The chapter begins by re-stating the overall aims of the thesis, followed by a synthesis of key findings. The limitations of the thesis research are then highlighted. A discussion of how this thesis has advanced scientific knowledge, along with the practical applications of the findings, is then presented. Finally, the research is viewed from a broader perspective, including health concerns associated with carbohydrate supplements and the role of these in the development of carbohydrate ingestion guidelines. This will also inform future research suggestions. The overall conclusions of the thesis are then stated.

7.1 Restatement of aims

This thesis investigated the influence of CHO ingestion immediately before, and during, prolonged intermittent, high-intensity exercise on the intermittent endurance capacity, sprint performance, and physiological responses of adolescent team games players. Initial research sought to establish the existence of an ergogenic effect with ingestion of a CHO-E solution. The influence of alterations in the [CHO] of ingested solutions was then studied, followed by investigation into supplementation of CHO in the form of a gel. In line with previous related work in adults, the thesis focussed on the influence of CHO supplementation on intermittent endurance capacity, sprint performance, and physiological response. This chapter provides a synthesised summary of the results from the three studies in this thesis. The practical applications of the results and the limitations of the studies are also discussed, and important avenues of future work are highlighted.

7.2 Experimental findings

7.2.1 Intermittent endurance capacity

Due to the results of previous studies on adults (sections 2.3.4 & 2.3.5) and current knowledge of CHO_{exo} oxidation during steady-state exercise in adolescents (section 2.1.5.3), it was initially hypothesised that CHO supplementation would significantly enhance intermittent endurance capacity in adolescent team games players. Study 1 found a significant 24.4% improvement in intermittent endurance capacity with ingestion of a 6% CHO-E solution compared with a PLA. Therefore, this hypothesised is supported. Study 2 reported a significant 34.1% enhancement in intermittent endurance capacity with ingestion of a 6% CHO-E solution compared to a 10% solution. A non-significant, but practically important, trend for greater intermittent endurance capacity was reported with ingestion of the 6% compared with the 2% solution, and the 2% compared with the 10% solution. The experimental hypothesis for this study is therefore supported. Finally, study 3 reported a significant 21.1% enhancement in intermittent endurance capacity with ingestion of a CHO gel that elicited the same BM-relative CHO intake to that of the 6% CHO-E solution in studies 1 and 2, supporting the experimental hypothesis for this study. The consistent observation throughout this thesis of a significant enhancement in intermittent endurance capacity ranging from 21.-24% with CHO ingestion compared to PLA provides strong evidence for a beneficial effect of CHO ingestion on this measure in adolescent team games players. Furthermore, within the confines of the CHO ingestion rates used in this thesis, the results indicate that ingestion of CHO at a rate of ~44-49 g, or 35-38 $g.h^{-1}$, equating to ~0.78 $g.kg^{-1}$ BM, or 0.58-0.63 $g.min^{-1}$, appears optimal for enhancing intermittent endurance capacity in these participants. This suggests that the CHO requirements of adolescents may be lower than those of adults during prolonged intermittent, high-intensity exercise (Jeukendrup, 2004; Jeukendrup & Jentjens, 2000), although the CHO amounts used in these studies were not orders of magnitude different from that in adult work. It may also be speculated that, had CHO ingestion in the current studies and previous adult work been compared relative to lean BM, the values may be even closer.

7.2.2 Sprint performance

The influence of CHO supplementation on sprint performance during simulated adult team games exercise is negligible, particularly when compared with the consistent observation of enhanced intermittent endurance capacity with CHO ingestion (section 2.3.5). Along with knowledge of the metabolic requirements of repeated short duration sprinting (Glaister, 2005) and the potentially greater fatigue resistance of adolescents compared with adults (section 2.1.6.2.1), the null hypothesis was that CHO ingestion would have no significant influence on sprint performance during prolonged intermittent, high-intensity exercise in adolescents. In studies 1 and 3, a clear trend for a non-significantly faster mean sprint and mean peak sprint time throughout exercise with CHO ingestion was apparent (section 4.3.3 & 6.3.3). At no time did the influence of CHO on any sprint variable become statistically significant. In study 2, while no statistically significant differences were found, moderate ES were reported for the main effect of CHO on mean sprint and mean peak sprint time (section 5.3.3). Therefore, while ingestion of CHO in the amounts and at the rates highlighted in section 7.2.3 does not maintain the sprint performance of adolescent team games players during prolonged intermittent, high-intensity exercise significantly better than a PLA, a potential practical benefit may exist. However, the data in this thesis supports the hypotheses for each study regarding this measurement.

7.2.3 Physiological response

Reviewing the adult literature on CHO supplementation before and during team games exercise led to the conclusion that CHO does not directly influence the overall physiological response to team games, as measured by $\dot{V}O_2$, HR, T_{core} and PV changes, BM loss and SR (section 2.3.6). As a result of this, it was hypothesised that CHO supplementation would not significantly influence the physiological response of adolescents to prolonged intermittent, high-intensity exercise. This expectation was almost fully realised, with no significant influence of CHO supplementation on BM loss or SR in any of the three studies. In fact, these variables were remarkably similar both between-trials in the same study, and between-studies. The negligible

influence of CHO on the physiological response to prolonged intermittent, high-intensity exercise is further reinforced by the lack of treatment effect on RPE, GF and GD measures, all of which can be influenced by alterations in physiological response, across the three studies. The only exception was peak HR at exhaustion in study 1, which was significantly greater in the CHO trial (section 4.3.4). This was initially hypothesised to be a metabolic and/or perceptual response to CHO supplementation in the adolescent participants that had not been previously found in adults during prolonged intermittent, high-intensity exercise. However, the absence of this finding in the two subsequent studies indicates that this may not be the case, and suggests that it may have been a specific outcome of the participant population used in study 1, or a statistical error. It appears that alterations in HR response at exhaustion is not an important mechanistic indicator, or requirement, for intermittent endurance capacity enhancement with CHO supplementation in adolescents. Carbohydrate supplementation did appear to exert a non-statistically significant indirect effect on HR response via a trend for a higher mean HR throughout part A of the LIST in studies 1 and 3 (section 4.3.4 & 6.3.4). This also corresponded with non-significantly faster mean sprint times in the CHO trial (section 4.3.3 & 6.3.3), which is a plausible explanation for the increased HR (section 2.3.7.1). However, when the findings of all three studies are collated, the evidence shows that ingesting CHO at rates of ~0.21-1.07 $g.min^{-1}$ (0.26-1.3 $g.kg^{-1}$ BM) does not significantly influence the HR responses of adolescent team games athletes to prolonged intermittent, high-intensity exercise.

7.2.4 Reliability of thesis findings

A summary of performance and physiological response data from all participants across all trials of each thesis study is shown in table 7.1. Additionally, data from the same variables, but only from the participants who took part in all three thesis studies, is shown in table 7.2. Similar values for intermittent endurance capacity were reported in the PLA trial for studies 1 and 3 (table 7.1). Intermittent endurance capacity in the CHO, MCHO, and CHO trials for studies 1, 2 and 3, respectively,

was also similar. In addition, intermittent endurance capacity in the CHO trial for study 1 and the MCHO trial for study 2 was almost identical (table 7.2).

Sprint times were very similar between-studies (table 7.1). When only the participants who took part in all thesis studies are considered, sprint times in study 1 were somewhat slower than those reported for studies 2 and 3 (table 7.2). However, it should be considered that study 2 was conducted approximately one year after study 1. Therefore, variables such as training status and biological maturation changes may account for this difference. This is supported by the similar sprint times between studies 2 and 3, which were only separated by approximately one month.

Both HR and RPE values were very similar within- and between-studies, when all participants (table 7.1) and only those who completed all thesis studies (table 7.2) were considered. Ratings of perceived exertion in particular displayed remarkable within- and between-studies consistency. Gut fullness and GD scores in the PLA trials for studies 1 and 3 were similar, as was the trend for a small increase in mean scores for both variables in the CHO trials within-studies.

The above analysis of data trends across all three thesis studies has highlighted consistent responses in measured variables across the studies. This indicates that the results of the studies conducted in this thesis were not generated by chance. Rather, it suggests that the protocols and methods employed were robust and well-controlled, and have produced consistent and reliable data that can be interpreted with confidence.

Table 7.1 Summary of performance and physiological response data of all participants for each thesis study. Data presented is that which was significantly influenced by treatment or time in at least one thesis study. Data are mean ± SD.

	Study 1		Study 2			Study 3	
Intermittent Endurance Capacity	CHO	PLA	LCHO	MCHO	HCHO	CHO	PLA
Time (min)	5.1 ± 1.8	4.1 ± 1.6	4.8 ± 1.2	5.5 ± 0.8	4.1 ± 1.5	4.6 ± 2.0	3.8 ± 2.4
Percentage difference	+ 24.4		+ 17.1[a]	+34.1[a] +14.6[b]		+ 21.1	
Sprint Times (s)	2.63 ± 0.24	2.66 ± 0.25	2.55 ± 0.26	2.56 ± 0.26	2.58 ± 0.30	2.58 ± 0.16	2.61 ± 0.22
Heart Rate (beats per min)	169 ± 10	166 ± 10	162 ± 7	166 ± 6	165 ± 7	162 ± 7	161 ± 10
Ratings of perceived exertion	7.1 ± 1.5	7.1 ± 1.5	6.1 ± 1.5	6.3 ± 1.5	6.4 ± 1.6	6.7 ± 1.5	6.7 ± 1.5
Gastric Disturbances							
Gut fullness	3.9 ± 1.7	3.7 ± 1.7	4.7 ± 1.3	4.2 ± 1.7	4.0 ± 1.3	4.8 ± 1.8	4.1 ± 1.4
Gastric discomfort	3.8 ± 2.3	3.3 ± 2.2	2.9 ± 1.3	3.2 ± 1.4	2.9 ± 1.6	3.9 ± 2.1	3.8 ± 2.1

CHO = carbohydrate trial; PLA = placebo trial; LCHO = low carbohydrate trial; MCHO = moderate carbohydrate trial; HCHO = high carbohydrate trial; [a] compared to HCHO trial; [b] Compared to LCHO trial

Table 7.2 Summary of performance and physiological response data of participants who completed all three thesis studies. Data presented is that which was significantly influenced by treatment or time in at least one thesis study. Data are mean ± SD, with *n* = 4 unless stated.

	Study 1		**Study 2**			**Study 3**	
Intermittent Endurance Capacity	CHO	PLA	LCHO	MCHO	HCHO	CHO	PLA
Time (min)	5.8 ± 3.0*	4.3 ± 1.7*	4.8 ± 1.2	5.9 ± 0.8	5.1 ± 1.6	4.1 ± 1.0	3.0 ± 0.4
Percentage difference	+ 34.9		+ 6.3[a]	+15.7[a] +22.9[b]		+ 36.6	
Sprint Times (s)	2.76 ± 0.33	2.77 ± 0.38	2.50 ± 0.30*	2.50 ± 0.25*	2.53 ± 0.27*	2.56 ± 0.21	2.61 ± 0.33
Heart Rate (beats per min)	171 ± 7	167 ± 6	163 ± 9	165 ± 4	165 ± 7	159 ± 4	159 ± 11*
Ratings of perceived exertion	7.5 ± 0.6	6.8 ± 0.9	6.3 ± 0.6	6.4 ± 0.8	6.5 ± 0.9	6.9 ± 0.3	6.5 ± 0.6
Gastric Disturbances							
Gut fullness	3.4 ± 1.4	3.3 ± 1.4	4.4 ± 1.3	4.2 ± 1.9	3.4 ± 1.2	3.8 ± 0.9	3.7 ± 1.2
Gastric discomfort	4.0 ± 2.7	3.4 ± 2.1	3.5 ± 0.7	3.3 ± 1.5	3.1 ± 1.2	3.1 ± 0.6	3.1 ± 1.4

CHO = carbohydrate trial; PLA = placebo trial; LCHO = low carbohydrate trial; MCHO = moderate carbohydrate trial; HCHO = high carbohydrate trial; * data is *n* = 3; [a] compared to HCHO trial; [b] Compared to LCHO trial

7.3 Limitations

The experimental research designs and associated protocols and measurements used within this thesis were robust. However, as with all research, there were some limitations that should be discussed.

7.3.1 Limitations applicable to all studies

7.3.1.1 Metabolic measurements

For ethical and consensual reasons, the metabolic response of participants during exercise could not be determined. This limitation did not affect the quality of the research or devalue it, but would have added an extra dimension by demonstrating not only an ergogenic effect of CHO supplementation, but also possibly quantifying, or refuting, mechanisms for this effect.

7.3.1.2 Assessment of biological maturation

Biological maturation of participants in this thesis was not assessed using the commonly held 'gold standard' method of direct observation of sexual characteristics, or via self-assessment of these characteristics. It could be argued that this constitutes a limitation of the thesis. However, the issues associated with observation of sexual characteristics as a method for quantifying maturation are highlighted in appendix 2. The method of biological maturation assessment used in this thesis has good validity, as discussed in section 3.2.3.

7.3.1.3 Age range and maturation status

A narrow age range was selected as a participant inclusion criterion in an attempt to reduce potential maturational influences (section 3.1) on CHO supplementation due to the difficulties inherent with accurate assessment of maturation status (appendix 2). Due to these procedural restrictions, the results of the thesis cannot be

confidently extrapolated to young people outside of the age range and biological maturation status of the participants used in these studies. This may be considered a potential limitation. However, this thesis was not specifically investigating the influence of age or maturation on CHO supplementation, primarily as this work represents the beginning of study in the field, and due to the issues associated with participant recruitment for investigations of this nature (section 7.3.2.2.1 & 7.3.2.2.2).

7.3.1.4 Mixed gender samples

Due to the inherent difficulties associated with recruitment of young people to research projects (appendix 1), young males and females were recruited in an attempt to maximise study sample sizes. This could be considered a limitation, as use of both genders may have increased variance in the data due to potential differences in physiological and metabolic responses to exercise between young males and females (D'Eon *et al*., 2002; Rowland *et al*., 1995; Timmons *et al*., 2007[b]; Turley, 1997). Unfortunately, gender comparisons could not be undertaken as an insufficient number of female participants were recruited for robust statistical analysis. However, as stated in sections 4.3 and 6.3, study data was analysed with and without the female participants data included, and it was confirmed that significance was not affected by inclusion of the female data.

7.3.1.5 Pre-exercise nutritional status

For logistical reasons, it was not possible to test all participants at the same time of day. Therefore, it was not possible to implement a pre-exercise fasting period, as has been done with some previous adult work (Ali *et al*., 2007; Davis *et al*., 1999; Davis *et al*., 2000; Nicholas *et al*., 1995). Pre-exercise nutritional status can impact substrate availability during exercise and influence exercise performance (Coyle *et al*., 1985; Neufer *et al*., 1987). The inability to standardise pre-exercise substrate availability between-participants in this thesis may have impacted on the results, perhaps by increasing data variance as a result of different pre-exercise nutritional

statuses. However, within-participants, pre-exercise dietary status was standardised. Furthermore, the data did show good consistency across the three studies (tables 7.1 & 7.2). Finally, the presence of an erogogenic effect of CHO ingestion in the absence of a pre-exercise fasting period may be considered a more ecologically valid finding, as it is unlikely that athletes will prepare for training or competition by fasting.

7.3.2 Study specific limitations

7.3.2.1 Study 1

7.3.2.1.1 Water trial

Although the first study in this thesis was robust, it may have been beneficial to incorporate an additional trial where each participant completed the LIST protocol while consuming standardised volumes of water. As this was the first study to put adolescent participants through a prolonged intermittent, high-intensity exercise protocol, this would have enabled quantification of the endurance capacity, sprint performance, and physiological response of the participants to the protocol without the possible psychological and perceptual influences of the blinded solutions. In addition, comparing data from the known water trial to the unknown CHO and PLA trials may have enabled a more detailed observation of the influence of solution perception on the various indices of performance during the LIST. However, it was not a main aim of this thesis to study potential influences of solution perception. Furthermore, in order to maximise participant recruitment and retention, it was necessary to limit the number of visits to the laboratory to those that were fully necessary to answer the specific research questions (section 7.3.2.2.1 & 7.3.2.2.2).

7.3.2.2 Study 2

7.3.2.2.1 Placebo trial

It is acknowledged that this study did not include a non-CHO PLA trial. While this would have been beneficial for comparative purposes, when working with adolescent participants it is necessary to strike an appropriate balance between formulating a robust research design and maximising the ability to recruit participants and retain them for the duration of the study. The protocols and participants in this study were the same as those used in study 1. It was not possible to re-recruit all participants from study 1 as some had exceeded the upper age limit for inclusion, and others did not wish to participate due to external commitments. The addition of a further visit in the form of a PLA trial would have exacerbated this issue, and would likely have resulted in more participants retiring from the study. The significant difference in intermittent endurance capacity between the CHO and PLA trials in study 1 was attained using a robust research design. Therefore, it is likely that a significant difference between the 6% CHO-E solution and PLA in study 2 would also have been reported. Consequently, it was decided to employ only the three CHO trials in order to address the research question.

7.3.2.2.2 Participant number

The participant number in study 2 was somewhat lower than studies 1 and 3, in part due to the issue discussed in the above section. While every attempt was made to maximise participant recruitment, it is acknowledged that a slightly higher participant number would have been desirable. However, a significant influence of CHO, along with clear trends and very large ES, on intermittent endurance capacity, as well as sprint performance and physiological response data that mimic the results of studies 1 and 3, were found. Furthermore, the first published studies into CHO supplementation before and during the standard LIST in adults used a mean participant number of $n = 8$ (Davis *et al*., 1999; Davis *et al*., 2000; Nicholas *et al*., 1995; Nicholas *et al*., 1999), which places the participant recruitment of this, and

studies 1 and 3, into context. Repeating study 2 with a larger participant number may be beneficial to corroborate the findings, and perhaps determine additional significant differences in intermittent endurance capacity between the different [CHO] (section 5.3.2 & 5.4.1). However, the importance of this study, its robustness, and its key findings reinforce its place within the context of this thesis and in establishing a foundation of knowledge in this new area of paediatric exercise physiology.

7.3.2.3 Study 3

Study 3 was conducted using the same research design and protocols as studies 1 and 2. Furthermore, the use of a taste and texture-matched PLA gel provided additional strength to the design that was not seen in the only previous study into CHO gel intake and prolonged intermittent, high-intensity exercise (Patterson & Gray, 2007). Therefore, aside from the overall thesis limitations discussed in section 7.3.1, there were no notable limitations of this study.

7.4 Advances in knowledge and practical applications

The studies in this thesis initiate an entirely new direction for research in paediatric exercise physiology. The findings in their entirety provide a new insight into the relationship between a participant population and form of exercise that frequently interact on a large scale, but until now have received almost no concurrent attention from the sports science research community. Crucially, this thesis serves to initiate the advancement of knowledge in the field of CHO supplementation and adolescent team games exercise, and begins to bridge the gap between adolescent participation in team games and the scientific knowledge to enable those participants to maximise their enjoyment and performance potential; an area of paediatric exercise science research that is hugely underrepresented. It also provides a foundation and stimulus for further research in this new field.

More specific to the area of CHO supplementation in adolescents, this thesis provides support for the use of CHO supplementation, in the form of a solution and a gel, and has begun the process of formulating guidelines regarding the optimal [CHO] that should be consumed by adolescent team games athletes. These results can be used to inform and support the ongoing CHO ingestion practices of adolescent team games athletes of the age and maturation range used in this thesis, or to encourage adolescent athletes to begin exploring CHO as a method of team games exercise enhancement where previously they had not, perhaps due to the lack of supporting evidence.

7.5 Wider perspectives on the research findings and suggestions for further work

The research in this thesis has provided novel data to support the ingestion of CHO immediately before, and during, prolonged intermittent, high-intensity exercise in adolescent team games players. It has also begun the process of formulating guidelines for CHO intake by this population during this form of exercise. This work is valuable, for the reasons discussed in section 7.4. Therefore, a tempting thought is to call for additional work to continue study into the manipulation of variables such as CHO composition, solution osmolality, and CHO ingestion rates (section 2.3.2) in order to further develop CHO ingestion guidelines for the youth team games population. Indeed, this work is important, as determination of the optimal CHO ingestion regime for young team games players would clearly be of great value.

However, focussing solely on optimising the composition of a CHO product consumed immediately before and during exercise is to ignore two key factors. One is the influence of nutritional intake in the hours prior to exercise on subsequent exercise performance, and the other is the potential health issues associated with frequent consumption of CHO-containing products, such as sports drinks. As has been discussed previously in this thesis, altering nutritional intake in the hours prior to exercise can significantly influence pre-exercise substrate status, exercise metabolism, and performance (Coyle *et al*., 1985; Neufer *et al*., 1987; Wright *et al*.,

1991). More specifically, ingesting natural, CHO-containing foods prior to exercise can elicit significant performance gains during prolonged intermittent, high-intensity exercise compared with low CHO intake (Bangsbo *et al*., 1992) or no food intake (Little *et al*., 2009; Little *et al*., 2010).

As discussed in section 2.3.3, a strong link is developing between the frequent ingestion of commercially available carbonated drinks, fruit juices, and sports drinks and erosion of dental enamel in young people (Al-Majed *et al*., 2002; Johansson *et al*., 2001; Luo *et al*., 2005; Lussi & Jaeggi, 2006). Furthermore, consumption of these products when the mouth is dry, or oral saliva content is attenuated, can exacerbate the issue (Shaw & Smith, 1999). Exercise can attenuate oral saliva production (Blannin *et al*., 1998). Therefore, ingestion of CHO-containing products during exercise could facilitate dental erosion. Unfortunately, consumption of these products during exercise periods is currently the recommended practice for young people who do wish to use them (American Academy of Pediatrics, 2011). In addition, routine intake of CHO-containing products such as sports drinks can lead to a significant increase in caloric intake (American Academy of Pediatrics, 2011). This increased caloric intake can substantially increase the risk for development of overweight and obesity in young people (Rodriguez *et al*., 2009), particularly in the absence of notable corresponding energy expenditure through exercise and physical activity. However, this risk would be dependent on the frequency and volume of consumption, and should not be used as a reason for preventing young people from using CHO-containing products. Rather, it should be factored into the development of guidelines for consumption.

Clearly, the potential health issues associated with ingestion of CHO-containing products in young people is a cause for concern when researching this topic in the youth population. It is morally and ethically important to evaluate the potential impact that this research may have on the general population and the youth population in particular. From this perspective, it is imperative that the positive findings, potential negative aspects, and knowledge limitations of the research are all communicated. Regarding the current work, a key question arises. Research exists

in adults to support the ingestion of appropriate pre-exercise meals for facilitating exercise performance and enhancement. There is also an increasing body of work that indicates frequent consumption of CHO-containing products such as sports drinks can significantly contribute to increased rates of dental enamel erosion, and the risk of developing overweight and obesity, in young people. Therefore, should young team games players be encouraged to consume CHO-containing products prior to every training session and match? The only appropriate answer is no.

However, this does not mean that the findings of this thesis are unimportant or should be ignored. An avenue of future research would be to investigate the influence of pre-exercise nutritional interventions on the performance of prolonged intermittent, high-intensity exercise by young people. Studying the influence of pre-exercise meals of differing energy content, energy composition, and glycaemic index would enable quantification of whether pre-exercise dietary intake can modulate exercise performance in young people, and if so, the optimum composition of natural foods required to maximise performance. Development of this research could then combine pre-exercise diet with ingestion of CHO-containing products during exercise, as has been done in adults (Chen *et al*., 2009; Chryssanthopoulos & Williams, 1997). This would develop guidelines for CHO ingestion before and during prolonged intermittent, high-intensity exercise that place the emphasis on appropriate natural dietary intake while also utilising the potential benefits of CHO supplements that have been documented in this thesis. However, the CHO supplements would be integrated as their name suggests, as supplements to the diet rather than as the main focus of nutritional interventions to maximise performance. This would facilitate ethical nutritional guidelines that seek to enhance the prolonged intermittent, high-intensity exercise performance of young people while also safeguarding their health and well-being.

7.6 Conclusions

The findings of this thesis demonstrate that ingestion of a 6% CHO-E solution immediately before, and during, prolonged intermittent, high-intensity exercise

significantly enhances the intermittent endurance capacity of adolescent team games players compared with a PLA and a 10% CHO-E solution. The thesis also identified that ingestion of a CHO gel, isoenergetic to that of a 6% CHO-E solution, significantly enhances intermittent endurance capacity compared with a PLA gel. Carbohydrate gel ingestion was analogous in efficacy to an iso-energetic CHO-E solution. No significant influence of CHO, in any medium or concentration, was observed on sprint performance during prolonged intermittent, high-intensity exercise. The influence of CHO on the physiological response of young team games players to prolonged intermittent, high-intensity exercise appears minimal, with the only reported effect being a significantly greater HR at exhaustion in study 1.

This thesis provides evidence to support the use of CHO before and during prolonged intermittent, high-intensity exercise designed to replicate the physiological demand of team games in adolescent team games players. Furthermore, it has begun to formulate guidelines for CHO ingestion by adolescent team games players, and provided a robust foundation for further study in this field. Continued development of guidelines should be the aim of future research, focussing primarily on the optimisation of pre-exercise meals for exercise enhancement, and investigating the use of CHO-containing products as supplements to this dietary regime. This will enable dissemination of ethically sound CHO ingestion guidelines that seek to maximise the exercise performance of young team games players while safeguarding their health and well-being.

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Appendices

Appendix 1: Issues of Ethics and Ethical Approval, Consent and Assent when Conducting Exercise Science Research In Young People

Conducting Exercise Science Research in Children and Adolescents

Research involving young people presents a set of unique challenges and requirements from an ethical, legal, and moral perspective, which must be understood and encompassed within a research paradigm. The following will present these issues in a descriptive style, highlighting the key concerns and how they should be addressed. Due to the comparative lack of information specifically related to exercise science research in young people, the majority of supporting literature is derived from policies and guidelines associated with medical therapeutic and non-therapeutic research.

1. Issues of ethics and ethical approval, consent and assent, recruitment and retention

1.1 Ethical approval

Early guidelines for conducting research in humans, stemming originally from the Nuremburg Code in an attempt to prevent the recurrence of experimentation such as that conducted by the Nazis, implemented doctrines and procedures that appeared to preclude young people from participating in research of any kind (Annas & Grodin, 1992; Jago & Bailey, 2001). However, more recently this view has been challenged, with the Medical Research Council (2004) stating that '…research involving children is essential for advancing child health and wellbeing. Often, it is not sufficient, scientific, or ethical to carry out research with adults and apply the findings to children'.

Despite the contemporary view that research involving young people is acceptable and, in many cases, necessary, the greater vulnerability of young people and their potential inability to give informed consent (section 1.1.1) increases the responsibility placed on those involved in the ethical approval process, including the research investigator, the local ethics committee, and the journal to which the research data are submitted (Robinson, 1987; Shephard, 2002). More specifically, it

is deemed acceptable for young people to participate in research if the relevant knowledge cannot be gained using adults, if they are exposed to no more than negligible risk of harm, if their interests always prevail over those of the research, and if they are not exposed to any form of coercion or pressure to continue the research against their or their parent's wishes (Medical Research Council, 2004). Regarding the extent of risk allowance associated with paediatric exercise research, it is plausible that ethical approval would be granted for obtaining blood samples (Jago & Bailey, 2001), probably pursuant to factors such as the frequency of sampling, importance of blood sampling to the research outcomes, and the age of the participants. In contrast, it is extremely unlikely that ethical approval would be given to carry out muscle biopsy work with young people in exercise research, regardless of the rationale (Armstrong & van Mechelen, 2008). When obtaining ethical approval to conduct exercise science research in young people it is imperative that the research proposal clearly demonstrates how the criteria for acceptable research are to be fulfilled (Jago & Bailey, 2001), and that should ethical approval be granted, how the appropriate procedures to protect and support the young participants will be strictly adhered. Jago and Bailey (2001) produced a checklist of questions that should be answered satisfactorily prior to making an ethics submission for exercise science research involving young people as participants (table 1).

Table 1 Questions that researchers' must answer satisfactorily before making an ethics submission for exercise science research involving young people as participants. Adapted: from Jago & Bailey (2001).

1.	Is the correct research question being asked?
2.	Can this research design answer the research question?
3.	Will the research provide valuable knowledge that cannot be gained using adults?
4.	Are there enough participants for statistical analysis?
5.	How will the participants be selected?
6.	Is the research therapeutic or non-therapeutic?
7.	Will consent, or consent and assent, procedures be used?
8.	How will the researcher ensure that consent is informed and what information will be provided and in what format (i.e. written and oral)?
9.	Is consent and assent provided freely, that is without actual or implied pressure or coercion?
10.	Does the research present no more than negligible risk and what can be done to alleviate or minimise the risk?
11.	Are the participants to be given opportunities to consider carefully the implications of participation before agreeing to take part?
12.	Have the participants been informed that they are able to withdraw at any time without any prejudice?
13.	Is there adequate insurance provision?
14.	Have the young participants completed a health-screening questionnaire and, if so, how long ago was it administered?
15.	When and where will the research be conducted and by whom?
16.	How will the results be disseminated?

1.1.1 Parental permission and child assent

The concept of consent is crucial in the process of gaining ethical approval and conducting ethical research in young people. Informed consent is a legal

requirement because under social rules and government legislation, the human body is regarded as inviolable (Sullivan, 1988). By this definition, one person cannot touch another person without their permission; doing so could leave an individual liable to prosecution for assault (Jago & Bailey, 2001). Regarding exercise physiology research, procedures such as collecting blood and urine samples, expired gas analysis, the attachment of heart rate (HR) chest monitors or muscle electrodes, and any number of other common testing procedures, could expose a researcher to this risk (Jago & Bailey, 2001). Therefore, obtaining consent is critical.

There are two main tenets in obtaining legal informed consent for research participation. The first is that consent must be provided freely, in the absence of any form of mental or physical coercion or inducement; the second is that consent must be based upon accurate information of the nature, risks and benefits of the research project (Jago & Bailey, 2001; Shephard, 2002). Therefore, the concept of informed consent presumes that the individual providing the consent is able to understand the information given to them, along with the possible implications of the research in which they will be involved. Clearly, some young people may not have this ability. Furthermore, children and young adolescents may not have the legal capacity to provide informed consent (Field & Behrman, 2005). Guidelines for non-therapeutic paediatric research are unclear, with the Medical Research Council (2004) stating that adolescents in England and Scotland between 16-18 years old are presumed competent to give consent. Similarly, the Royal College of Paediatrics and Child Health (2000) state that the agreement of school age children to take part in research should be requested by researchers. Jago and Bailey (2001) discuss that when conducting exercise science research with individuals younger than 18 years, the researcher must assess the ability of the individual to provide consent, and be aware of the possibility of prosecution should their interpretation be deemed incorrect. For these reasons, the concepts of informed parental permission and child assent have been developed (Diekema, 2006; Field & Behrman, 2005).

For most research involving young people, parental permission is a legal and/or ethical requirement (Ungar *et al*., 2006). The process of obtaining parental

permission should follow the same procedures as gaining informed consent (Diekema, 2006), and should include the provision to the parents of information regarding the purpose, procedures, risks and benefits of the research in non-scientific language, and a clear statement that their child's participation is voluntary and can be withdrawn at any time without penalty (Diekema, 2006). Every attempt must be made by the researchers to identify possible sources of confusion from the parents regarding the research, and to alleviate these concerns (Diekema, 2006; Field & Behrman, 2005). As with informed consent, the process of gaining parental permission must be free of coercion (Diekema, 2006). Along with parental permission, the researcher must consider the concept of child assent, defined as a child's affirmative agreement to participate in the research (Ungar *et al*., 2006). Any child who has reached the age of 7 years, or equivalent mental maturity, is able to provide assent (Nicholson, 1986). Child assent does not equate to informed consent; rather, it reflects the belief that even though the child may not fully understand or consider all of the implications of research participation, their level of understanding and decision-making ability are sufficient to decide whether they would like to participate (Diekema, 2003). Child assent is not legally binding (Jago & Bailey, 2001), but it is beneficial from the point of view of making the young person feel included and that they have a voice within the research process. It also respects their maturity, helps them prepare for participation, and helps them express any worries or concerns (Field & Behrman, 2005). Researchers should provide basic information about what will happen, what is expected of the young person within the project, respond to questions, and recognise when a participant does not really want to participate (Field & Behrman, 2005). As with parental permission, the process of child assent must be free of coercion. It should also be considered that even if ethical approval for a particular procedure or test has been obtained, if parental permission and/or child assent is not granted, that procedure cannot be performed. Ethical approval does not preclude parental permission or child assent.

At its best, child assent is an interactive process involving the investigator, parents, and participant with the goal of assuring that the young person has at least some understanding of the study purpose, procedures and possible risks, and is most

important when the research procedures directly involve the young person (Diekema, 2006). Furthermore, when combined with parental permission, it allows the research to be both legally and morally valid (Jago & Bailey, 2001). The combination of parental permission and child assent enables the conduct of morally and ethically sound exercise science research with individuals aged 7 to 16 years (Jago & Bailey, 2001).

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Appendix 2: Common Methods of Biological Maturation Assessment

1. Biological maturity status

Chronological age is a poor indicator of biological maturation status (Armstrong, 2007). However, the influence of biological maturation on physiological and metabolic variables, and hence exercise performance, is significant, particularly at 12-15 years, when participation in youth sport is at its peak (Armstrong & McManus, 2011; McManus & Armstrong, 2011). Therefore, research involving young people should implement appropriate and valid procedures to assess biological maturation, in order to quantify the influence of this variable on physiological responses to exercise. While a multitude of procedures, with differing levels of validity and objectivity, exist for the assessment of biological maturation, equipment availability and ethical restrictions make many of these procedures impractical or inappropriate for use in non-clinical research. The following sections provide a critical discussion of the most common methods of biological maturity assessment.

1.1 Skeletal age assessment

Skeletal age assessment is a prevalent maturity indicator, particularly in clinical settings, as it is the only development indicator available from birth to adult maturity (Cox, 1997). The three most common skeletal age assessment methods are the Greulich-Pyle atlas (GPA), Tanner-Whitehouse 2 (TW2), and Fels methods. These methods are not interchangeable, and skeletal maturity values differ between the three (Bull *et al*., 1999; Gilli, 1996; Van Lenthe *et al*., 1998). Furthermore, each method holds numerous potential issues and sources of error (table 1). In addition, a recent systematic review and meta-analysis of these three methods confirmed that skeletal age assessment using only x-ray analysis of the hand and wrist are not accurate, and additional analyses such as physical examinations and dental assessments would be required (Serinelli *et al*., 2011). In light of this, the following issues associated with using these maturation assessment methods in young people are most prevalent. Firstly, most validity studies of skeletal maturation assessment methods have occurred in a clinical setting using a large cross-sectional population. The applicability of the methods to highly physically active and well-trained

adolescents has not been established. This is important when considering that regular physical activity during childhood and adolescence, particularly during the adolescent growth spurt, is associated with significantly greater bone mineral content and peak velocity of bone mineral accrual compared with inactive participants of the same age (Hills *et al*., 2007; Vicente-Rodriguez *et al*., 2005). Secondly, the potential variations in reliability and accuracy with an inexperienced practitioner means that the validity of the data collected may be questionable, and could require further validation from a more experienced practitioner. Thirdly, exposing young people to x-rays in order to collect potentially invalid data that could be obtained using alternative methods would pose a serious ethical issue, and may also preclude parental consent from being granted. Fourthly, the equipment necessary to conduct skeletal age assessment is not widely available.

Table 1 The main limitations associated with the three most prevalent methods of skeletal age assessment. Data from: Berst *et al*. (2001), Cox (1997), Gilli (1996), Mora *et al*. (2001), Roche & Johnson (1969), Schmidt *et al*. (2008), Van Lenthe *et al*. (1998), Verma *et al*. (2009).

Assessment Method	Limitations
Greulich-Pyle Atlas	• Standard radiographs were collected from healthy, white, upper-middle class American males and females 70-80 years ago. May affect validity when applied to contemporary children and different ethnicities • Most radiographic standards include bones that differ considerably in maturity levels, which may affect reliability • Lack of standardised technique hampers cross-validation of method and comparison of study results • Radiographic standards are at 6 month intervals, reducing accuracy of assigning skeletal age • Participant radiographs cannot in every case be assigned to the standards with full agreement • Method is based on a developmental rate of one skeletal year for each chronological year. There is no evidence to suggest that this developmental rate characterises entire period of osseous development • Reliability and accuracy of method may be dependent on experience of administrator • Interpretation of radiograph can be affected by prior knowledge of participants chronological age
Tanner-Whitehouse 2	• Poor positioning of hand can alter appearance of epiphysis and make interpretation of radiograph difficult • Multiple stages of maturation have been developed, leading to use of criteria that describe minor changes in bone development, but are not true maturity indicators • At upper end of maturity scale, skeletal maturity can be greatly affected by small differences in judgement of individual bone age • Method is relatively difficult to learn and may promote excessive reliance on the bone illustrations rather than written descriptions, possibly leading to diagnostic errors • Current differentiation of stages of development of radius and ulna are thought to be too approximate • Skeletal maturity scores were assigned to each development criteria arbitrarily and do not consider inter-individual differences in the presence of maturity indicators
Fels	• Paucity of literature examining validity and reliability of the method • Lack of cross-validation studies available • Work that does exist shows significant difference in skeletal maturation data from Tanner-Whitehouse 2 method • Method only provides bone-specific bone ages, not a skeletal maturity score

1.2 Sexual maturation

Sexual maturation is quantified by assessing indices of secondary sexual characteristics including breast development in girls, genitalia development and testicular volume in boys, pubic hair development in both genders, and other aspects including facial hair, axillary hair, voice change, body odour, body shape and menarche (Baxter-Jones *et al*., 2005). The stages of breast, genitalia and pubic hair development are divided into five stages, commonly termed Tanner stages after the detailed descriptions published by Tanner (1962).

Determination of sexual maturity has traditionally been obtained through direct visual observation of secondary sexual characteristics (Baxter-Jones *et al*., 2005), usually by a physician. However, this method can be an uncomfortable experience for the participant and may be deemed unacceptable by parents, precluding parental consent. In this situation, it is possible for young people to complete a self-assessment based on standardised photographs of the five Tanner stages (Malina *et al*., 2004). This appears to have good reliability (Chan *et al*., 2008; Chan *et al*., 2010; Matsudo & Matsudo, 2005; Wacharasindhu *et al*., 2002), although young people may overestimate early stages and underestimate late stages of development (Schlossberger *et al*., 1992). However, the option of self-assessment is not necessarily going to be more palatable than direct observation to a young participant or their parents, again raising the issue of consent.

Observation of secondary sexual characteristics is desirable because it does not require longitudinal observations, is easy to administer, cost effective and, when self-assessment is employed, non-invasive (Baxter-Jones *et al*., 2005). However, as Baxter-Jones *et al*. (2005) discuss, the method is not without problems. There is a notable difference in the timing and tempo of sexual maturation between genders (Sherar *et al*., 2004), and these differences are not appreciated in the current standards for secondary sexual staging. For example, a boy at stage 2 for genital development is not necessarily the same biological age as a girl at stage 2 of breast development, and neither is a girl at stage 2 of breast development necessarily at

stage 2 of pubic hair development (Baxter-Jones *et al*., 2005). Therefore, comparing between genders, or within genders using different indices, is potentially inaccurate. Finally, the commonly used pubic hair stages for classifying biological maturation represent the onset of adrenarche (increased production of sex hormones), not necessarily the onset of puberty itself (Baxter-Jones *et al*., 2005; Tanner, 1962).

While observation of secondary sexual characteristics is, when carried out appropriately, a potentially strong indicator of biological maturity, it is difficult to justify its use in a non-clinical setting where it can be extremely uncomfortable for the participant and the researcher. Furthermore, it is likely that both the direct and self-assessment methods would encounter strong resistance either at the institutional ethical approval, parental consent, or child assent level, and perhaps all three.

1.3 Prediction of biological maturation from morphological age

Height reached at any given chronological age can be compared with reference values to assess maturity (Baxter-Jones *et al*., 2005). However, this method is not valid for assessment of biological maturity as it fails to take into account variability in population height (Baxter-Jones *et al*., 2005). For example, figure 1 shows that at age 7 and 14 years, male B is ~10 and 18 cm shorter, respectively, than males A and C. Using a morphological scale, male B would therefore be classified as a late maturer (Armstrong, 2007). However, he may be shorter simply because he is going to be shorter than average as an adult, not necessarily due to the timing of his growth spurt. This is reinforced when expressing height as a percentage of adult height, which accounts for the natural variability in height amount individuals (Armstrong, 2007). In this situation male B, despite in absolute terms appearing small for his age, does not differ from male C at 7 or 14 years of age (figure 1). This is explained by the fact that at 40 years of age, male B is some 15 cm shorter than male C. An obvious disadvantage of this method is that an adult height is required, therefore biological maturity can only be assessed with full confidence retrospectively (Baxter-Jones *et al*., 2005).

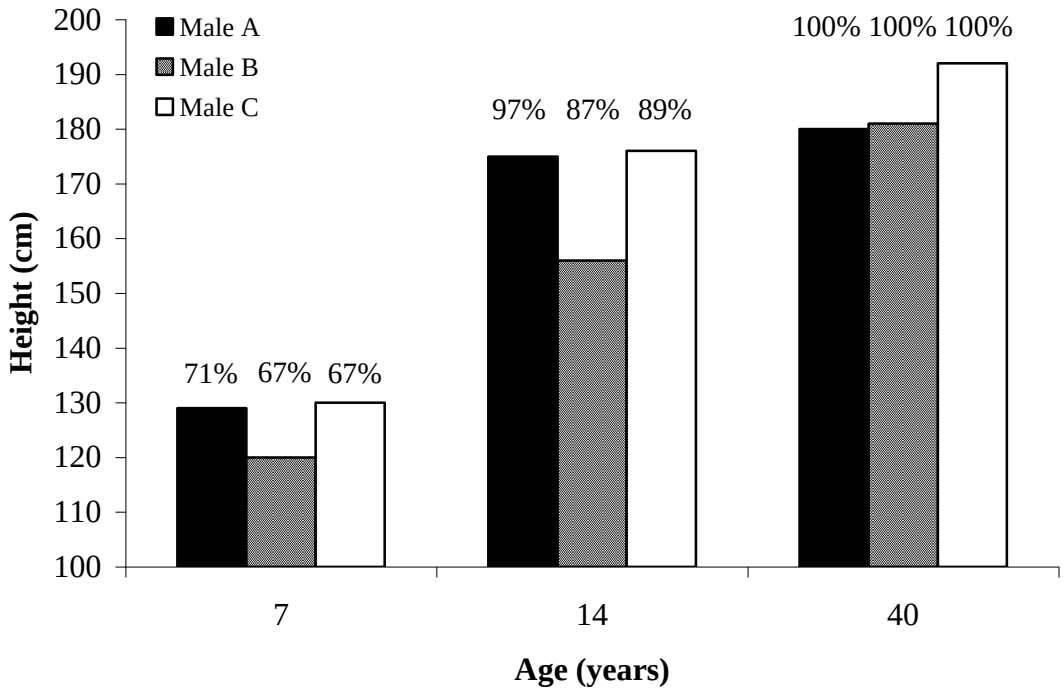

Figure 1 Actual height and percentage of adult height of three males at ages 7, 14 and 40 years. The issues associated with inferring biological maturation status by measuring height alone during childhood, with no reference to final adult height, can be seen. Figure adapted from: Baxter-Jones *et al*. (2005), data from: Mirwald (1980).

While prediction of adult height could be used to quantify current height in adolescents, most common methods of predicting adult height require a measure of skeletal age, limiting their practicality. Beunen *et al*. (1997) developed age-specific multiple regression equations to predict adult height in Flemish boys aged 13-16 years using four somatic dimensions (current stature, sitting height, subscapular skinfold, triceps skinfold) and chronological age, negating the requirement for skeletal age assessment. Further validation studies of the equations have produced correlations between predicted and actual adult height of r = 0.70-0.85 with a standard error of the estimate of 3.3-4.7 cm (Beunen *et al*., 2010), and between percentage of predicted adult height and skeletal maturity using the Fels method of r = 0.52 (Malina *et al*., 2007) in a sample of youth American football players. While these correlations were significant, they are not particularly strong. Indeed, Malina

et al. (2007) could only conclude that percentage of predicted adult height is a 'reasonably valid estimate' of biological maturity.

1.4 Age at peak height velocity

The most commonly used somatic milestone in longitudinal paediatric growth studies is age at peak height velocity (APHV; Baxter-Jones *et al*., 2005). To obtain APHV, whole-year height-velocity increments are plotted and mathematical curve fitting procedures used to determine the age at which maximal velocity of statural growth occurs (Armstrong, 2007; figure 2). There is a large variance in the occurrence of peak height velocity (PHV) in relation to chronological age, occurring on average at age 12 (range 9.5-14.5) years in girls and 14 (range 10.5-17.5) years in boys (Baxter-Jones *et al*., 2005).

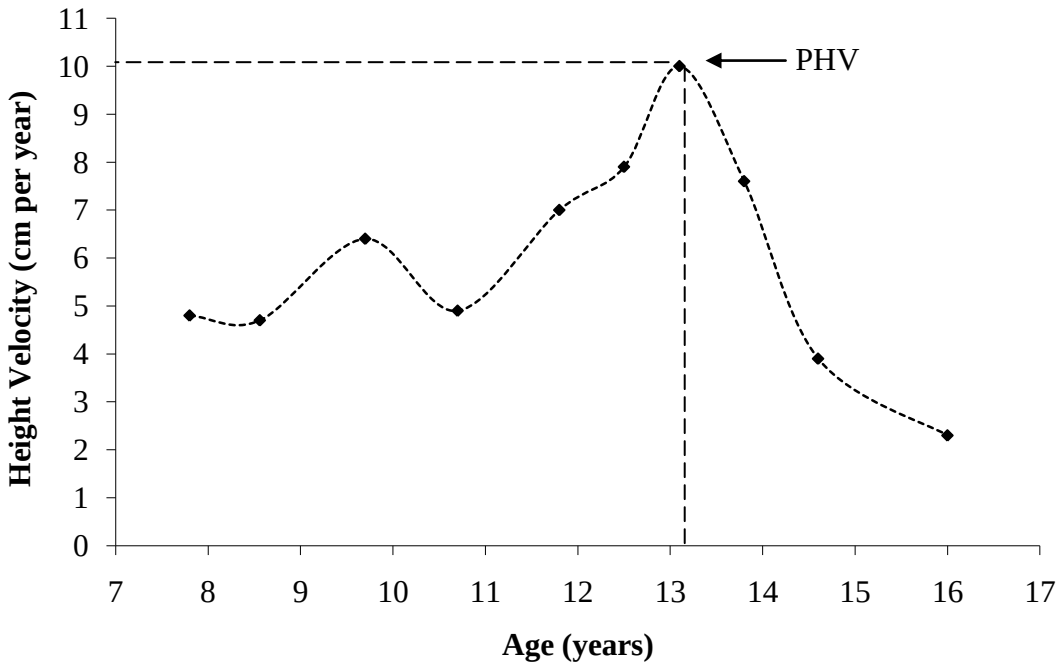

Figure 2 Example of whole-year height velocities plotted against chronological age to determine age at peak height velocity. In this example, a peak height velocity of 10 cm per year occurs at ~ 13.1 years. Adapted from: Baxter-Jones *et al*. (2005).

When an individual reaches APHV they have a biological age equal to 0.0 years from PHV. At 11 years, an individual who reaches PHV at 12 years has a biological

age of -1.0 year from PHV, and at 13 years has a biological age of +1.0 year from PHV. Therefore, individuals can be aligned and compared based on biological age as opposed to chronological age. Additionally, individuals can be classified as early, average, or late maturers. Early maturers have an APHV ≥ 1 year less than the mean APHV and late maturers have an APHV of ≥ 1 year greater than the mean APHV, with the rest classed as average maturers (Baxter-Jones *et al*., 2005). The obvious disadvantage with this method is that serial measures of height over several years are required in order to create the necessary height-velocity increments. Therefore, this method of biological maturity assessment is only applicable to longitudinal research.

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Appendix 3: Ethical Approval Confirmations and Participant Recruitment Forms

A3.1 Ethical approval confirmation for studies 1-3

Study 1

From: John Sproule 24 April 2009 10:28:55

Subject: study 1 ethics

To: **Shaun M. Phillips**

Hi Shaun,

This is to confirm level 2 ethical approval for your study 1, in my role as your principal PhD supervisor.

John

John Sproule PhD,
University of Edinburgh.

www.education.ed.ac.uk/staff-profile/john-sproule/index.html
www.education.ed.ac.uk/pesls/
www.sport.ed.ac.uk/

Email: john.sproule@ed.ac.uk
Tel: 0131 6516135

Studies 2 and 3

MORAY HOUSE SCHOOL *of* EDUCATION
The University of Edinburgh
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Edinburgh EH8 8AQ

Telephone 0131 650 1000
or direct dial 0131 651
Fax 0131 651 6688
Email Education@ed.ac.uk
Website http://www.ed.ac.uk

Mr. Shaun Phillips
PESLS
St Leonard's Land

17th December 2009

Dear Shaun

The effect of ingesting a carbohydrate gel on the prolonged intermittent exercise performance and capacity of 12-14 year old team sport players and

The influence of carbohydrate concentration on the prolonged intermittent exercise performance and capacity of adolescents

The School of Education Ethics Sub-Committee has now considered your request for ethical approval for the studies detailed in your application.

This is to confirm that the Sub-Committee is happy to approve the application and that the research meets the School Ethics Level 3 criterion. This is defined as "applied to research which is potentially problematic in that it may incorporate an inherent physical or emotional risk to participants".

You are reminded that if the research changes in anyway from that described on your application form, you may need to re-apply for approval.

Yours sincerely

pp. Dr K McCulloch
Convener, School Ethics Sub-Committee

A3.2 Example cover letter to parents for studies 1-3

Study 1

Dept. Physical Education, Sport & Leisure
Moray House School of Education
St Leonards Land
Holyrood Road
Edinburgh
EH88AQ
Tel: 0131 650 9788
Mob: 07792 337639
Email: shaun.m.phillips@education.ed.ac.uk

January 2009

Dear sir / madam

My name is Shaun Phillips, and I am carrying out my PhD studies at University of Edinburgh. I am investigating whether drinking carbohydrate drinks such as Lucozade Sport improves the exercise performance of adolescents. I recently organised a trip to Inverleith Hockey club and spoke to some of the players about taking part in this research, and your son has expressed an interest. Therefore, I am writing to request your permission for your son to take part in this project.

Enclosed with this letter is a full information sheet detailing the purpose of the research, the role of your son within the project, risks and benefits of participation, and the safety measures and confidentiality procedures that will be employed throughout the process. This should give you all the information you require, however should you have any additional concerns or questions please feel free to contact me on the details at the top of this letter.

Upon receiving your permission, I will contact you to arrange dates and times for your son to come along to the University. The first visit will last approximately 90 min, and the subsequent two visits approximately 2 hours each. I will schedule the visits so that they are most suited to you and your son. As mentioned on the enclosed information sheet, you do not need to remain at the University for the duration of the visits.

Let me take this opportunity to reinforce that the safety and well-being of project volunteers is paramount. Your son will be at all times supervised by fully trained, experienced members of University of Edinburgh staff. While it is crucial that the research is carried out in an accurate and professional manner, every attempt will be made to ensure that your son has an enjoyable, interactive and educational experience.

Your consideration to allow your son to participate in this project is deeply appreciated. Once you have had a chance to look at the information sheet, if you are happy for your son to participate could you please fill in and sign the enclosed consent form and post it in the stamped envelope provided. You may keep all other forms for your own information. Once again, thank you very much for your interest in this research, and please do not hesitate to contact me if you require any further information.

Kind regards

Shaun Phillips
PhD research student

Study 2

Dept. Physical Education, Sport & Leisure
Moray House School of Education
St Leonards Land
Holyrood Road
Edinburgh
EH88AQ
Tel: 0131 650 9788
Mob: 07792 337639
Email: S.M.Phillips@sms.ed.ac.uk

January 2010

Dear sir / madam

My name is Shaun Phillips, a PhD student at University of Edinburgh. I am currently investigating whether drinking carbohydrate drinks such as Lucozade Sport improves the performance of 12-14 year old team sports players. I recently spoke with coaching staff at Hibernian FC's training centre who gave me permission to distribute information packs regarding taking part in this research. It would be fantastic if your son would like to take part.

Enclosed with this letter is a full information sheet detailing the purpose of the research, the role of your son within the project, benefits of participation, and the safety and confidentiality procedures that will be employed. This should give you all the information you require, however should you have any additional concerns or questions please feel free to contact me on the details at the top of this letter.

Upon receiving your permission, I will contact you to arrange dates and times for your son to come along to the University. There are only four visits, each of which will last approximately 2 hours. I will schedule the visits so that they are most suited to you and your son. As mentioned on the enclosed information sheet, you do not need to remain at the University for the duration of the visits.

Let me take this opportunity to reinforce that the safety and well-being of project volunteers is paramount. Your son will be at all times supervised by fully trained, experienced members of University of Edinburgh staff. While it is crucial that the research is carried out in an accurate and professional manner, every attempt will be made to ensure that your son has an enjoyable, interactive and educational experience.

Your consideration to allow your son to participate in this project is deeply appreciated. Once you have had a chance to look at the information sheet, if you are happy for your son to participate could you please fill in, sign the enclosed permission slip, and post it at your earliest convenience in the stamped envelope provided. You may keep all other forms for your own information. Once again, thank you very much for your interest in this research, and I hope I will have the opportunity to involve your son in a project that will help to improve his performance in his chosen sport.

Kind regards

Shaun Phillips
PhD research student

Study 3

Dept. Physical Education, Sport & Leisure
Moray House School of Education
St Leonards Land
Holyrood Road
Edinburgh
EH88AQ
Tel: 0131 650 9788
Mob: 07792 337639
Email: S.M.Phillips@sms.ed.ac.uk

May, 2010

Dear sir / madam

My name is Shaun Phillips, a PhD student at University of Edinburgh. I am currently investigating whether drinking carbohydrate drinks such as Lucozade Sport improves the performance of 12-14 year old team sports players. I recently spoke with coaching staff at Forresters Rugby Club who gave me permission to distribute information packs regarding taking part in this research. It would be fantastic if your son would like to take part.

Enclosed with this letter is a full information sheet detailing the purpose of the research, the role of your son within the project, benefits of participation, and the safety and confidentiality procedures that will be employed. This should give you all the information you require, however should you have any additional concerns or questions please feel free to contact me on the details at the top of this letter.

Upon receiving your permission, I will contact you to arrange dates and times for your son to come along to the University. There are only three visits, each of which will last approximately 2 hours. I will schedule the visits so that they are most suited to you and your son. As mentioned on the enclosed information sheet, you do not need to remain at the University for the duration of the visits.

Let me take this opportunity to reinforce that the safety and well-being of project volunteers is paramount. Your son will be at all times supervised by fully trained, experienced members of University of Edinburgh staff. While it is crucial that the research is carried out in an accurate and professional manner, every attempt will be made to ensure that your son has an enjoyable, interactive and educational experience.

Your consideration to allow your son to participate in this project is deeply appreciated. Once you have had a chance to look at the information sheet, if you are happy for your son to participate could you please fill in, sign the enclosed permission slip, and post it at your earliest convenience in the stamped envelope provided. You may keep all other forms for your own information. Once again, thank you very much for your interest in this research, and I hope I will have the opportunity to involve your son in a project that will help to improve his performance in his chosen sport.

Kind regards

Shaun Phillips
PhD research student

A3.3 Example parental project information sheet for studies 1-3

Study 1

Physical Education, Sport & Leisure Studies

Participant Information Sheet – Parental Copy

Project title: The effect of ingesting a 6% carbohydrate-electrolyte solution during a simulated game sports protocol on the exercise performance and capacity of adolescents.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Purpose:

It has been known for many years that consuming a drink containing carbohydrate and electrolytes (sodium, potassium, chloride etc) such as Lucozade Sport prior to and during exercise of 1 hour or more can improve performance (how much work can be completed), and capacity (how long you can exercise before exhaustion). Recently this beneficial effect has been seen when people perform intermittent exercise for prolonged periods, i.e. the 'stop-start' exercise characteristic of game sports such as football, rugby, hockey etc. While this effect has been observed in adults, no research has been conducted to see if the effects are the same in adolescents, a large number of whom take part in game sports on a regular basis. Therefore, the aim of this research project is to observe whether consumption of a carbohydrate-electrolyte drink before and during intermittent exercise has any effect on adolescents' exercise performance and capacity.

What is required of your daughter?

Prior to inclusion in this study, your daughter will complete a medical screening questionnaire. This is a completely normal procedure to ensure that she is suitable for this study and that participation will not put her at any risk. To collect the data needed to answer the research question, your daughter will take part in three structured exercise sessions. The tests are designed to replicate the demands typical of game sports, therefore will not place her under any more physical or psychological stress than she experiences when taking part in these sports. More information on this is provided in the 'risks and benefits' section below. Testing will take place over three days in St Leonard's Land, Holyrood Road (date and time to be confirmed) with the visits be separated by a minimum of three and maximum of seven days to

avoid fatigue affecting the measurements. Prior to each testing session, your daughter will be supervised through a 10-minute warm-up on a treadmill followed by stretching of the hamstrings (back of the thigh), quadriceps (front of the thigh) and calf muscles.

Day 1

Your daughter will be familiarised with the treadmill that will be used for the preliminary tests carried out on this day. She will complete a warm up followed by the first four levels of an incremental running speed test. The warm up will last for 5 min at a speed of 8 kilometres per hour. After this, the speed will be increased by 0.5 kilometres per hour every minute for 4 minutes. Each speed increase is equivalent to one level. After a 10 minute seated rest, she will complete this incremental test, beginning at 8 kilometres per hour and increasing each minute, until she can no longer keep running despite verbal encouragement from the investigator. This is termed volitional fatigue (see risks and benefits section). At this point, she will be asked to walk slowly on the treadmill for 5 minutes to recover, and then will sit and relax until fully recovered. This test is carried out to find her maximal running speed, which will then be used to calculate the running speeds required for the main exercise tests (see Day 2 & 3).
After approximately 15 minutes recovery your daughter will take part in the Loughborough Intermittent Shuttle Run Test (LIST; see below for details) for 15 min in order to get used to this exercise protocol.

Day 2 & 3

On day 2, your daughter will attend the laboratory where she will be given either a carbohydrate-electrolyte drink or a placebo 5 minutes before starting the LIST. The LIST is a shuttle running exercise over 20 metres that is composed of four 15 minute blocks of walking, jogging, high-intensity running and sprinting, with a 3 minute recovery period between each block (part A). As mentioned, this is designed to replicate the demands of game sports. Following the final block, alternating 20 metre shuttles of jogging and high-intensity running is completed for as long as possible, until volitional exhaustion is reached (part B). The LIST can be summarised as:

Part A:

1. 3 x 20 metres at walking pace
2. 1 x 20 metres at maximum running speed
3. 3 x 20 metres at speed corresponding to 55% maximum running speed
4. 3 x 20 metres at speed corresponding to 95% maximum running speed

This sequence is repeated until 15 minutes has expired.

Part B:

1. 1 x 20 m at 55% maximum running speed
2. 1 x 20 m at 95% maximum running speed

This sequence is repeated until the participant can no longer maintain the required speed.

On completion of part B, your daughter will be taken through a thorough cool down and allowed to sit and rest until completely recovered. On day 3, exactly the same protocol as above will be followed, except she will consume the second drink. It is extremely important that your daughter take part in both tests using the two drinks.

Inclusion Criteria

In order to take part in this study, your daughter should be:

A. Regularly active in game sport exercise
B. Between the ages of 12 and 14
C. Free from any muscle or joint injury or other condition that restricts her ability to exercise
D. In good general health
E. Free from medication that restricts her ability to exercise

A more thorough medical questionnaire will be provided on acceptance of participation.

Potential Benefits and Risks

Data will be collected that reveals your daughter's level of fitness and provides information about how her heart and lungs are functioning during exercise specific to her chosen sporting activity. This could be of interest, and could be used to improve her performance via more focussed and effective training. On request, your daughter can receive feedback on her performance upon completion of all three test days.
The risks involved in this study are minimal. They include possible fatigue, muscle soreness and muscle strain. However, these are all situations that are encountered with regular participation in sports. Exercising to volitional fatigue is common in exercise studies, and carries virtually no risk in a healthy individual. The activities your daughter will be required to undertake are not different to those she would carry out both in game sports training and competition. Indeed, they are specifically designed to replicate these activities.

Safety Measures

In a healthy, physically active individual, strenuous and maximal exercise presents virtually no health issues. Additionally, when exercising to volitional fatigue your daughter, by definition, will decide when she wants to stop the exercise. She will be encouraged to continue, but will never be forced to do so. While on the University

premises she will be supervised at all times by the principal investigator of the study, who is trained and experienced at using all equipment and measurement devices employed in the research, as well as being trained in emergency first aid. The principal investigator has also successfully completed the Disclosure Scotland background check, and for your daughter's comfort, will be accompanied by a female assistant during the sessions. All equipment used has been specifically designed and safety tested for the activities it will be used for in the study, and is well maintained. Your daughter will have the opportunity to ask as many questions as she wants to. Obviously full completion of the study by each participant is important and greatly appreciated, however, *your daughter will not be forced into undergoing any aspect of the research, and is free to stop, and withdraw from the study, at any time without explanation*.

Confidentiality

Information received in this study is regarded as confidential both during and after the conclusion of the investigation and will only be viewed by the principal investigator and his supervisory team, who are all University staff members and are bound by the same confidentiality regulations. All completed forms will be kept in a locked filing cabinet. The experimental data collected will be used for future publication but will be anonymous so that your daughter will not be identifiable in any way. If you have further questions, please contact the principal investigator on the details below.

Thank you for your time,

Shaun Phillips
Tel: (0131) 6509788
Mob: 07792 337639
Email: shaun.m.phillips@education.ed.ac.uk

Study 2

Physical Education, Sport & Leisure Studies

Participant Information Sheet – Parental Copy

Project title: The influence of ingesting different CHO concentrations during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Purpose:

It has been demonstrated that drinking carbohydrate drinks such as Lucozade Sport can improve performance when adults take part in intermittent exercise for prolonged periods, i.e. the 'stop-start' exercise characteristic of team sports such as football, rugby, hockey etc. Recent work here at Edinburgh University has also shown this to be the case when adolescents (12-14 years old) take part in this form of exercise. However, the optimal intake of carbohydrate for adolescents is currently unknown. The aim of this research project is to investigate the influence of consuming different carbohydrate concentrations on the prolonged intermittent exercise performance of adolescents.

What is required of your son?

Initially, your son will complete a medical screening questionnaire. This is a normal procedure to ensure his safe participation in the study. To collect the necessary data, your son will take part in four structured exercise sessions. The exercise replicates the demands of team sports, therefore will not place him under any more physical or psychological stress than he experiences when taking part in these sports (see 'risks and benefits'). Testing will take place over four days in St Leonard's Land, Holyrood Road (dates and times to be confirmed) with *each visit separated by a minimum of three and maximum of seven days* to avoid fatigue affecting the measurements. Prior to each session, your son will be supervised through a 10-minute warm-up and stretching session.

Day 1 (Duration: 2 hours)

Your son will firstly be familiarised with the treadmill that will be used on this day. Following a 10 minute seated rest, he will then complete an incremental running test. The treadmill speed will start at 8 kph and increase by 0.5 kph each minute, until he can no longer keep running despite verbal encouragement from the investigator. This is termed volitional fatigue (see risks and benefits section). At this point, he will be asked to walk slowly on the treadmill for 5 minutes to recover, and then will sit and relax until fully recovered. This test is conducted to find his maximal running speed, which will then be used to calculate the running speeds required for the main exercise tests (see Day 2, 3 & 4).
After approximately 15 minutes recovery your son will take part in the Loughborough Intermittent Shuttle Run Test (LIST; see below for details) for 15 min to familiarise him with this exercise protocol.

Day 2, 3 and 4 (Duration: 2 hours each)

On day 2, your son will attend the laboratory where he will be given one of the three drinks 5 min before starting the LIST:

1. Low-carbohydrate – similar carbohydrate level to 'Lucozade Hydro'sports drink
2. Moderate-carbohydrate – similar carbohydrate level as 'Lucozade Sport' sports drink
3. High-carbohydrate – higher carbohydrate level than 'Lucozade Sport' sports drink

The LIST is a shuttle running exercise over 20 metres composed of four 15 minute blocks of walking, jogging, high-intensity running and sprinting, with a 3 minute recovery period between each block (part A). As mentioned, this is designed to replicate the demands of game sports. Following the final block, alternating 20 metre shuttles of jogging and high-intensity running are completed until volitional exhaustion (part B). The LIST can be summarised as:

Part A:

1. 3 x 20 metres at walking pace
2. 1 x 20 metres at maximum running speed
3. 3 x 20 metres at speed corresponding to 55% maximum running speed
4. 3 x 20 metres at speed corresponding to 95% maximum running speed

This sequence is repeated until 15 minutes has expired.

Part B:

1. 1 x 20 m at 55% maximum running speed
2. 1 x 20 m at 95% maximum running speed

This sequence is repeated until the participant can no longer maintain the required speed.

On completion of part B, your son will be taken through a thorough cool down and allowed to sit and rest until completely recovered. On day 3 and 4, he will complete the same exercise while drinking the other two drinks. It is therefore very important that your son take part in all sessions using all drinks, so that his results can be used in the project.

Inclusion Criteria

In order to take part in this study, your son should be:

1. Regularly active in team sport exercise
2. Between the ages of 12 and 14
3. Free from any muscle or joint injury or other condition that restricts his ability to exercise
4. In good general health
5. Free from medication that affects his ability to exercise

Potential Benefits and Risks

Data will be collected that reveals your son's level of fitness and provides information about how his heart and lungs are functioning during exercise specific to his chosen sporting activity. This could be used to improve his performance via more focussed and effective training. On completion of the project, your son will receive personalised feedback on his performance.
The risks involved in this study are minimal. They include possible fatigue, muscle soreness and muscle strain. However, these are all situations that are encountered during regular participation in sports. Exercising to volitional fatigue is common in exercise studies, and carries virtually no risk in a healthy individual. The activities your son will be required to undertake are not different to those he would carry out both in team sports training and competition. Indeed, they are specifically designed to replicate these activities.

Safety Measures

It is important to state that the drinks used in this study are based on commercially available products, contain ingredients that are routinely ingested in a normal balanced diet, and pose no risk to a healthy individual. The principal investigator would be happy to provide more information on request, if required.
When exercising to volitional fatigue your son, by definition, will decide when he wants to stop. He will be encouraged to continue, but will ***never*** be forced to do so. While on the University premises he will be supervised at all times by the principal investigator of the study, who is trained and experienced at using all relevant equipment and measurement devices, and is trained in emergency first aid. The principal investigator has also successfully completed the Disclosure Scotland background check. Your son will have the opportunity to ask as many questions as he wants to. Obviously full completion of the study by each participant is important and greatly appreciated, however, *your son will not be forced into undergoing any*

aspect of the research, and is free to stop, and withdraw from the study, at any time without explanation.

Confidentiality

Information received in this study is regarded as confidential both during and after the investigation and will only be viewed by the principal investigator and his supervisory team, who are all University staff members bound by the same confidentiality regulations. All completed forms will be kept in a locked filing cabinet. The experimental data collected will be used for future publication but your son will not be identifiable in any way. If you have further questions, please contact the principal investigator on the details below.

Thank you for your time,

Shaun Phillips
Tel: (0131) 6509788
Mob: 07792 337639
Email: S.M.Phillips@sms.ed.ac.uk

Study 3

Physical Education, Sport & Leisure Studies

Participant Information Sheet – Parental Copy

Project title: The effect of ingesting a carbohydrate gel before and during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Purpose:

Recently it has been shown that drinking carbohydrate drinks such as Lucozade Sport can improve performance when people take part in intermittent exercise for prolonged periods, i.e. the 'stop-start' exercise characteristic of team sports such as football, rugby, hockey etc. Recent work in adults has also shown that ingesting carbohydrate in the form of a gel elicits similar improvements to that of carbohydrate drinks. Gels are becoming more commonplace in sport and exercise, both with adults and young people. However, the effects of these gels on the exercise performance of young people has yet to be investigated. Therefore, the aim of this research project is to investigate whether consumption of a carbohydrate gel before and during prolonged intermittent exercise influences the exercise performance of adolescents.

What is required of your daughter?

Initially, your daughter will complete a medical screening questionnaire. This is a normal procedure to ensure her safe participation in the study. To collect the necessary data, your daughter will take part in three structured exercise sessions. The exercise replicates the demands of team sports, therefore will not place her under any more physical or psychological stress than she experiences when taking part in these sports (see 'risks and benefits'). Testing will take place over three days in St Leonard's Land, Holyrood Road (dates and times to be confirmed) with *each visit separated by a minimum of three and maximum of seven days* to avoid fatigue affecting the measurements. Prior to each session, your daughter will be supervised through a 10-minute warm-up and stretching session.

Day 1 (Duration: 2 hours)

Your daughter will firstly be familiarised with the treadmill that will be used on this day. Following a 10 minute seated rest, she will then complete an incremental running test. The treadmill speed will start at 8 kph and increase by 0.5 kph each minute, until she can no longer keep running despite verbal encouragement from the investigator. This is termed volitional fatigue (see risks and benefits section). At this point, she will be asked to walk slowly on the treadmill for 5 minutes to recover, and then will sit and relax until fully recovered. This test is conducted to find her maximal running speed, which will then be used to calculate the running speeds required for the main exercise tests (see Day 2 & 3).
After approximately 15 minutes recovery your daughter will take part in the Loughborough Intermittent Shuttle Run Test (LIST; see below for details) for 15 min to familiarise her with this exercise protocol.

Day 2 & 3 (Duration: 2 hours each)

On day 2, your daughter will attend the laboratory where she will be given either a carbohydrate gel or a placebo gel, along with water, 10 minutes before starting the LIST. The LIST is a shuttle running exercise over 20 metres composed of four 15 minute blocks of walking, jogging, high-intensity running and sprinting, with a 3 minute recovery period between each block (part A). As mentioned, this is designed to replicate the demands of game sports. Following the final block, alternating 20 metre shuttles of jogging and high-intensity running are completed until volitional exhaustion (part B). The LIST can be summarised as:

Part A:

1. 3 x 20 metres at walking pace
2. 1 x 20 metres at maximum running speed
3. 3 x 20 metres at speed corresponding to 55% maximum running speed
4. 3 x 20 metres at speed corresponding to 95% maximum running speed

This sequence is repeated until 15 minutes has expired.

Part B:

1. 1 x 20 m at 55% maximum running speed
2. 1 x 20 m at 95% maximum running speed

This sequence is repeated until the participant can no longer maintain the required speed.

On completion of part B, your daughter will be taken through a thorough cool down and allowed to sit and rest until completely recovered. On day 3, she will follow the same protocol, except she will consume the second gel. It is therefore very important that your daughter take part in all sessions using all drinks, so that her results can be used in the project.

Inclusion Criteria

In order to take part in this study, your daughter should be:

1. Regularly active in game sport exercise
2. Between the ages of 12 and 14
3. Free from any muscle or joint injury or other condition that restricts her ability to exercise
4. In good general health
5. Free from medication that affects her ability to exercise

Potential Benefits and Risks

Data will be collected that reveals your daughter's level of fitness and provides information about how her heart and lungs are functioning during exercise specific to her chosen sporting activity. This could be used to improve her performance via more focussed and effective training. On completion of the project, your daughter will receive feedback on her performance.

The risks involved in this study are minimal. They include possible fatigue, muscle soreness and muscle strain. However, these are all situations that are encountered with regular participation in sports. Exercising to volitional fatigue is common in exercise studies, and carries virtually no risk in a healthy individual. The activities your daughter will be required to undertake are not different to those she would carry out both in team sports training and competition. Indeed, they are specifically designed to replicate these activities.

Safety Measures

It is important to state that the gels used in this study are commercially available and contain the same ingredients as carbohydrate drinks (primarily fruit juice, water, and carbohydrate), just in a gel form. They contain ingredients that are routinely ingested in a normal balanced diet, and pose no risk to a healthy individual. The principal investigator would be happy to provide more information on request, if required.

When exercising to volitional fatigue your daughter, by definition, will decide when she wants to stop. She will be encouraged to continue, but will never be forced to do so. While on the University premises she will be supervised at all times by the principal investigator of the study, who is trained and experienced at using all relevant equipment and measurement devices, and is trained in emergency first aid. The principal investigator has also successfully completed the Disclosure Scotland background check, and for your daughter's comfort, will be accompanied by a female assistant during the sessions. Your daughter will have the opportunity to ask as many questions as she wants to. Obviously full completion of the study by each participant is important and greatly appreciated, however, *your daughter will not be forced into undergoing any aspect of the research, and is free to stop, and withdraw from the study, at any time without explanation*.

Confidentiality

Information received in this study is regarded as confidential both during and after the investigation and will only be viewed by the principal investigator and his supervisory team, who are all University staff members bound by the same confidentiality regulations. All completed forms will be kept in a locked filing cabinet. The experimental data collected will be used for future publication but your daughter will not be identifiable in any way. If you have further questions, please contact the principal investigator on the details below.

Thank you for your time,

Shaun Phillips
Tel: (0131) 6509788
Mob: 07792 337639
Email: shaun.m.phillips@education.ed.ac.uk

A3.4 Example parental permission slip for studies 1-3

Study 1

Permission Slip

The influence of ingesting a 6% carbohydrate solution during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players

I give permission for my son to take part in the above titled research project. Please call me on the number below to discuss this further, and arrange dates and times for his visits to the University.

……	……	……
Signed	**Your Name**	**Your son's name & age**
……	**(Morning / afternoon / evening)**	……
Tel. No.		**Your son's school / club**

Study 2

Permission Slip

The influence of ingesting solutions of differing carbohydrate concentration during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players

I give permission for my son to take part in the above titled research project. Please call me on the number below to discuss this further, and arrange dates and times for his visits to the University.

……	……	……
Signed	**Your Name**	**Your son's name & age**
……	**(Morning / afternoon / evening)**	……
Tel. No.		**Your son's school / club**

Permission Slip

The influence of ingesting a carbohydrate gel during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players

I give permission for my son to take part in the above titled research project. Please call me on the number below to discuss this further, and arrange dates and times for his visits to the University.

…….	…….	…….
Signed	**Your Name**	**Your son's name & age**
…….	**(Morning / afternoon / evening)**	…….
Tel. No.		**Your son's school / club**

A3.5 Example parental informed consent form for studies 1-3

Study 1

Physical Education, Sport & Leisure Studies

Parental Consent form

Project title: The effect of ingesting a 6% carbohydrate-electrolyte solution during a simulated game sports protocol on the exercise performance and capacity of adolescents.

Investigator: Shaun Phillips

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Participant Name: ..... **Participant No:**.....

- I have read and understood the project information sheet.
- I understand what the project is about and what the results will be used for.
- I am fully aware of all of the procedures my child will be involved in and of any risks and benefits associated with the study.
- I am fully aware of, and satisfied with, the safety procedures in-place during the project.
- I understand that the results of the project may be published but that my child's name or identity will not be revealed.
- I know that my child's participation is voluntary and that they can withdraw from the project at any stage without giving any reason.
- I am aware that my child's results will be kept confidential.
- I consent to my child's participation in this research project.

Parent / Guardian name (print): ……

Parent / guardian signature : ……

Investigator signature : ……

Date: …….....

Contact Details

In case we need to contact you while your child is on the University premises, could you please provide the following information:

Name : ……

Address : …….

…….

…….

…….

Contact tel. number (daytime) : ……..

Contact email: .....

Would you like to be informed of the dates and times your son will be attending the university once these have been confirmed?

Yes / No

If yes, which contact method would you like us to use to give you this information?

Telephone / email

Study 2

Physical Education, Sport & Leisure Studies

Parental Consent form

Project title: The influence of ingesting different CHO concentrations during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players.

Investigator: Shaun Phillips

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Participant Name: ..... **Participant No:**.....

- I have read and understood the project information sheet.
- I understand what the project is about and what the results will be used for.
- I am fully aware of all of the procedures my child will be involved in and of any risks and benefits associated with the study.
- I am fully aware of, and satisfied with, the safety procedures in-place during the project.
- I understand that the results of the project may be published but that my child's name or identity will not be revealed.
- I know that my child's participation is voluntary and that they can withdraw from the project at any stage without giving any reason.
- I am aware that my child's results will be kept confidential.
- I consent to my child's participation in this research project.

Parent / Guardian name (print): ……

Parent / guardian signature : …….

Investigator signature : ……

Date: …….....

Contact Details

In case we need to contact you while your child is on the University premises, could you please provide the following information:

Name : ……

Address : …….

……

……

……

Contact tel. number (daytime) : ……..

Contact email: .....

Study 3

Physical Education, Sport & Leisure Studies

Parental Consent form

Project title: The effect of ingesting a carbohydrate gel before and during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players

Investigator: Shaun Phillips

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Participant Name: ..... **Participant No:**.....

- I have read and understood the project information sheet.
- I understand what the project is about and what the results will be used for.
- I am fully aware of all of the procedures my child will be involved in and of any risks and benefits associated with the study.
- I am fully aware of, and satisfied with, the safety procedures in-place during the project.
- I understand that the results of the project may be published but that my child's name or identity will not be revealed.
- I know that my child's participation is voluntary and that they can withdraw from the project at any stage without giving any reason.
- I am aware that my child's results will be kept confidential.
- I consent to my child's participation in this research project.

Parent / Guardian name (print): ……

Parent / guardian signature : ……

Investigator signature : ……

Date: …….....

Contact Details

In case we need to contact you while your child is on the University premises, could you please provide the following information:

Name : ……

Address : …….

……

……

……

Contact tel. number (daytime) : ……..

Contact email: .....

A3.6 Example participant project information sheet for studies 1-3

Study 1

Physical Education, Sport & Leisure Studies

Participant Information Sheet – Participant Copy

Project title: The effect of ingesting a 6% carbohydrate-electrolyte solution during a simulated game sports protocol on the exercise performance and capacity of adolescents.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Purpose:

When you drink carbohydrate drinks (like Lucozade Sport) before and during games like football, rugby, hockey etc you can play better and keep going for longer. However, this has only been proved when adults do it. Many people in your age group take part in game sports, and drink things like Lucozade Sport while doing it, so it is important to find out if these drinks have any benefit to people of your age. That is what this project is going to find out.

What you will need to do:

Before you can take part, you will fill in a questionnaire just to check that it is safe for you to take part. This is completely normal and nothing to worry about. Once that is done, you will take part in three exercise sessions. These will all be done on separate days. The exercises you will do are specially chosen so that they copy the kind of activity you do when you play game sports. Because of this, they should feel quite familiar to you and you should feel comfortable doing them.

Day 1

On this day, you will be shown how to run on the treadmill. The treadmill will only be used on this day. To practice you will run for 5 minutes at a slow speed. Once you have done that, you will have a rest for 5 minutes. Then you will do a test to see how fast you can run. You will start running at a slow speed, and each minute the speed will be increased a little. You will keep going until you cannot possibly keep running any further, no matter how hard you try. After you have had a rest from this, you will have a practice at the main exercise test for 15 minutes. You will do this test on day 2 and day 3.

Day 2 & 3

The next day you come in, you will do the computer test and then be given a drink before you exercise. There are two drinks in this experiment; they will look, smell and taste the same but they are different, and you won't be told which drink you get each time. After you've drunk it, you will start exercising. The exercise you will do is shuttle running in the sports hall. You will do walking, jogging, sprinting, and fast running and the person in charge will tell you when to do each activity, so you won't have to remember anything. You will do this for 15 minutes, and then have a 3-minute rest. Then you will do the same 15 minutes three more times, with a 3 minute rest each time. After that, you will do fast running then jogging as many times as you can, until you cannot possibly keep running anymore. After that you can sit down and rest.
On day 3, you will do exactly the same as this, except you will be given the second drink.

Benefits and Risks

We will collect information that tells us how fit you are when you do game sports. This could help you become better by telling you what things you are good at and what things you need to work on.
When you do this type of exercise you might feel tired afterwards, and you might get sore muscles. This is normal and will probably feel the same as how you feel after playing sports.

Things to Remember

- If you have any questions at all, just ask
- If you are not sure what you need to be doing, just ask and we can go through it
- There's no need to be nervous!
- Give it your best effort

Thank you for your time,

Shaun Phillips
Tel: (0131) 6509788
Mob: 07792 337639
Email: shaun.m.phillips@education.ed.ac.uk

Study 2

Physical Education, Sport & Leisure Studies

Participant Information Sheet – Participant Copy

Project title: The influence of ingesting different CHO concentrations during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Purpose:

When adults drink carbohydrate drinks (like Lucozade Sport) before and during games like football, rugby, hockey etc you can play better and keep going for longer. We recently found out that this is also true when people of your age drink these drinks. However, we don't know how much carbohydrate is best for people of your age to take in when playing these sports. That is what this project is going to find out.

What you will need to do:

Before you can take part, you will fill in a questionnaire just to check that it is safe for you to take part. Once that is done, you will take part in four exercise sessions. These will all be done on separate days. The exercises you will do copy the kind of activity you do when you play team sports. Because of this, they should feel quite familiar to you and you should feel comfortable doing them.

Day 1

On this day, you will be shown how to run on the treadmill. The treadmill will only be used on this day. You will have a practice on the treadmill, and once you are comfortable you have a rest for 10 minutes. Then you will do a test to see how fast you can run. You will start running at a slow speed, and each minute the speed will be increased a little. You will keep going until you cannot possibly keep running any further, no matter how hard you try. After you have had a rest from this, you will have a practice at the main exercise session for 15 minutes. You will do this session on day 2 and day 3.

Day 2, 3 & 4

The next day you come in, you will be given a drink before you exercise. There are three drinks in this experiment; they will look, smell and taste the same but they are different, and you won't be told which drink you get each time. After you've drunk it, you will start exercising. The exercise you will do is shuttle running in the sports hall. You will do walking, jogging, sprinting, and fast running and the person in charge will tell you when to do each activity, to help you remember. You will do this for four lots of 15 minutes, with each lot separated by a 3-minute rest. After that, you will do fast running then jogging as many times as you can, until you cannot possibly keep running anymore. Once you decide you can't keep going, you will stop and then sit down and rest. On day 3 and 4, you will do exactly the same as this, except you will be given the other drinks.

Benefits and Risks

We will collect information that tells us how fit you are when you do game sports. This could help you become better by telling you what things you are good at and what things you need to work on.
When you do this type of exercise you might feel tired afterwards, and you might get sore muscles. This is normal and will probably feel the same as how you feel after playing sports.

Things to Remember

- If you have any questions at all, just ask
- If you are not sure what you need to be doing, just ask and we can go through it
- There's no need to be nervous!
- Give it your best effort

Thank you for your time,

Shaun Phillips
Tel: (0131) 6509788
Mob: 07792 337639
Email: shaun.m.phillips@education.ed.ac.uk

Physical Education, Sport & Leisure Studies

Participant Information Sheet – Participant Copy

Project title: The effect of ingesting a carbohydrate gel before and during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Purpose:

When you drink carbohydrate drinks (like Lucozade Sport) before and during games like football, rugby, hockey etc you can play better and keep going for longer. Also, eating carbohydrate gels can be as good as drinking carbohydrate drinks. However, this has only been proved when adults do it. Many people in your age group take part in team sports, and eating carbohydrate gels while doing it is becoming more popular, so it is important to find out if these gels have any benefit to people of your age. That is what this project is going to find out.

What you will need to do:

Before you can take part, you will fill in a questionnaire just to check that it is safe for you to take part. Once that is done, you will take part in three exercise sessions. These will all be done on separate days. The exercises you will do copy the kind of activity you do when you play team sports. Because of this, they should feel quite familiar to you and you should feel comfortable doing them.

Day 1

On this day, you will be shown how to run on the treadmill. The treadmill will only be used on this day. You will have a practice on the treadmill, and once you are comfortable you have a rest for 10 minutes. Then you will do a test to see how fast you can run. You will start running at a slow speed, and each minute the speed will be increased a little. You will keep going until you cannot possibly keep running any further, no matter how hard you try. After you have had a rest from this, you will have a practice at the main exercise session for 15 minutes. You will do this session on day 2 and day 3.

Day 2 & 3

The next day you come in, you will be given a gel to eat before you exercise. There are two gels in this experiment; they will look, smell and taste the same but they are different, and you won't be told which gel you get each time. After you've eaten it, you will start exercising. The exercise you will do is shuttle running in the sports hall. You will do walking, jogging, sprinting, and fast running and the person in charge will tell you when to do each activity, to help you remember. You will do this for four lots of 15 minutes, with each lot separated by a 3-minute rest. After that, you will do fast running then jogging as many times as you can, until you cannot possibly keep running anymore. Once you decide you can't keep going, you will stop and then sit down and recover. On day 3, you will do exactly the same as this, except you will be given the second gel.

Benefits and Risks

We will collect information that tells us how fit you are when you do game sports. This could help you become better by telling you what things you are good at and what things you need to work on.
When you do this type of exercise you might feel tired afterwards, and you might get sore muscles. This is normal and will probably feel the same as how you feel after playing sports.

Things to Remember

- If you have any questions at all, just ask
- If you are not sure what you need to be doing, just ask and we can go through it
- There's no need to be nervous!
- Give it your best effort

Thank you for your time,

Shaun Phillips
Tel: (0131) 6509788
Mob: 07792 337639
Email: shaun.m.phillips@education.ed.ac.uk

A3.7 Example child assent form for studies 1-3

Study 1

Physical Education, Sport & Leisure Studies

Child Assent form

Project title: The effect of ingesting a 6% carbohydrate-electrolyte solution during a simulated game sports protocol on the exercise performance and capacity of adolescents.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Participant Name: ..... **Participant No:**.....

- I understand that my parents have given permission for me to take part in a project about the effects of drinking a carbohydrate drink on how well you complete game sports exercise, carried out by Shaun Phillips, a PhD student at the University of Edinburgh.
- I have read the information sheet, and I know what the project is about and what the results will be used for.
- I know what I am needed to do during the project.
- If other people see the results of the project they will not know that I took part, and no-one except the people in charge of the project will see my results.
- I know that if I haven't been told any of this, or I don't agree with any of it, then I don't have to sign this form.
- I am taking part in this project of my own free will. I have had the chance to ask any questions that I might have, and I have been told that I can stop taking part at any time and everything will be fine.

…….. ……

Signature **Date**

Study 2

Physical Education, Sport & Leisure Studies

Child Assent form

Project title: The influence of ingesting different CHO concentrations during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Participant Name: ..... **Participant No:**.....

- I understand that my parents have given permission for me to take part in a project about the effects of drinking different carbohydrate drinks on how well you complete game sports exercise, carried out by Shaun Phillips, a PhD student at the University of Edinburgh.
- I have read the information sheet, and I know what the project is about and what the results will be used for.
- I know what I am needed to do during the project.
- If other people see the results of the project they will not know that I took part, and no-one except the people in charge of the project will get to see my results.
- I know that if I haven't been told any of this, or I don't agree with any of it, then I don't have to sign this form.
- I am taking part in this project of my own free will. I have had the chance to ask any questions that I might have, and I have been told that I can stop taking part at any time and everything will be fine.

…….. ……

Signature **Date**

Study 3

Physical Education, Sport & Leisure Studies

Child Assent form

Project title: The effect of ingesting a carbohydrate gel before and during a simulated team sports protocol on the intermittent exercise performance and capacity of 12-14 y old team sports players.

Investigator: Shaun Phillips, PhD research student.

Co-investigators: Dr Tony Turner & Dr Shirley Gray

Participant Name: ..... **Participant No:**.....

- I understand that my parents have given permission for me to take part in a project about the effects of eating a carbohydrate gel on how well you complete game sports exercise, carried out by Shaun Phillips, a PhD student at the University of Edinburgh.
- I have read the information sheet, and I know what the project is about and what the results will be used for.
- I know what I am needed to do during the project.
- If other people see the results of the project they will not know that I took part, and no-one except the people in charge of the project will get to see my results.
- I know that if I haven't been told any of this, or I don't agree with any of it, then I don't have to sign this form.
- I am taking part in this project of my own free will. I have had the chance to ask any questions that I might have, and I have been told that I can stop taking part at any time and everything will be fine.

…….. ……

Signature **Date**

Appendix 4: Data Collection Forms and Scales

A4.1 Example participant medical questionnaire for studies 1-3

Physical Education, Sport and Leisure Studies

Pre-Test Medical Questionnaire

Participant Number: .....

Please answer the questions below as honestly as you can. Don't worry, the information is private and won't be shown to anyone. Also, if you don't understand a question or you want any help at all, just ask.

Please answer the questions by putting a circle around your answer, or filling in the blank.

1. **Do you smoke?** Yes / No

   If you answered yes, please write how many cigarettes you smoke on an average day.....

2. **Do you drink alcohol?** Yes / No

   If you answered yes, please circle the answer the applies to you:

   I drink occasionally / I have a drink every day / I have more than one drink a day

3. **Have you gone to see your doctor in the last six months?** Yes / No

   If you answered yes, please write down why you went to see your doctor:

   …….....

   …….....

4. **Have you needed to go to hospital in the last year?** Yes / No

   If you answered yes, please write down why you went to hospital:

   ……....

   ……

5. Are you taking any medicines at the moment? Yes / No

If you answered yes, please write down what the medicine is called and why you are taking it:

……

6. Has playing sport or doing exercise ever made you become ill in any way? Yes / No

If you answered yes, please tell the person in charge and they will ask you anything they need to.

7. If you have any of these conditions, please circle yes. If you have had any of these conditions in the past, you must also circle yes. If you have never had the condition, circle no.

Diabetes	Yes / No
Epilepsy	Yes / No
Any heart problems	Yes / No
Asthma	Yes / No
Bronchitis	Yes / No
Any other lung problem	Yes / No
Pain in your chest	Yes / No
Blood clots	Yes / No
Hepatitis	Yes / No
HIV	Yes / No
Any other blood problem	Yes / No
Pains in your stomach	Yes / No
Dizziness	Yes / No
Headaches	Yes / No
Feeling very tired for no reason	Yes / No

Do you have any other conditions that are not included on this list? Yes / No

If you answered yes, please write down what these conditions are:

……

……

8. **Do you currently have any pain, discomfort or injury in your muscles?** Yes / No

9. **Do you currently have any pain, discomfort or injury in your joints or bones?** Yes / No

Thank you for filling in this questionnaire. Please sign your name below.

Participant signature: …….

Investigator Signature: ……..

Date: …….

University of Edinburgh
19/2/2009/S Phillips

A4.2 Example food diary for studies 1-3

Please write down EVERYTHING you eat and drink for 24 hours before you come to the university to exercise. Please write clearly so that you can use this list to eat and drink the same things for 24 hours before your second exercise session.

Time	Description	Amount / size / weight
5pm	Pepperoni pizza, salad (lettuce, coleslaw, cucumber, tomato), chips, ice cream, orange juice	3 medium slices, one handful lettuce, two table spoons coleslaw, 4 slices cucumber, 1 small tomato, 50 grams chips, 3 table spoons ice cream, 1 medium glass OJ

A4.3 Example data collection form for the V_{peak} test for studies 1-3

Study 1 – V_{peak} Test Data Sheet

Participant Number: ……... Weight (kg): …….

Age: ……. Date: …….

Height (cm): …… Time: ……

Temperature (^{o}C): …….. Humidity: …….

Time (min)	Speed (kph)	HR (bpm)	RPE
0-1	8		
1-2	8.5		
2-3	9		
3-4	9.5		
4-5	10		
5-6	10.5		
6-7	11		
7-8	11.5		
8-9	12		
9-10	12.5		
10-11	13		
11-12	13.5		
12-13	14		
13-14	14.5		
14-15	15		
15-16	15.5		
16-17	16		

V_{peak}: ……..... 55% V_{peak}: ……

HR_{MAX}: …….. 95% V_{peak}:……..

A4.4 Example data collection form for the Loughborough Intermittent Shuttle Test

Study 1 – Experimental Trial Data Sheet

Participant Number:…… Trial ID:……..

Date:…….. 95% $V_{peak:}$……..

Time of Trial:…… 55% V_{peak}:……...

Sitting Height (cm): ..... Body mass (kg): .....

PART A

Time	RPE	Gut Fullness	Gastric Discomfort
End of 15 min (1)			
End of 15 min (2)			
End of 15 min (3)			
End of 15 min (4)			
Mean			

Heart Rate

Download data from watch **immediately** after trial

Distance Covered

No of completed cycles of the LIST per block. 1 cycle = from 1st walk shuttle to last 95% V_{peak} shuttle. Also write details of partially completed cycles (1 full cycle = 200m)

	Block 1	Block 2	Block 3	Block 4

Sprint Times

Sprint No.	Block 1	Block 2	Block 3	Block 4
1				
2				
3				
4				
5				
6				
7				

8				
9				
10				
11				
12				
Mean				

PART B

RPE (exhaustion)	**Gut Fullness (exhaustion)**	**Gastric Discomfort (exhaustion)**

Heart Rate

Download data from watch **immediately** after trial

Distance Covered

No of completed shuttles up to exhaustion (put a mark for each shuttle, 1 mark = 20 m)

Time to exhaustion: ……

Body mass (kg): ……..

Total fluid intake:

5 x = ml
2 x = ml x 4 =

Temperature and Humidity

	Temperature	Humidity
Pre-trial	.....	.....
End of Block 1	.....	.....
End of Block 2	.....	.....
End of Block 3	.....	.....
End of Block 4	.....	.....

Participants drink decisions (do after each trial):

Trial 1: .....

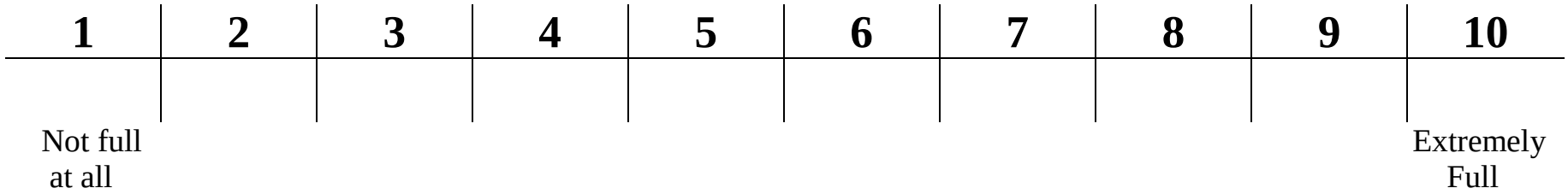
Trial 2: .....

A4.5 Children's omnibus walk/run scale of perceived exertion

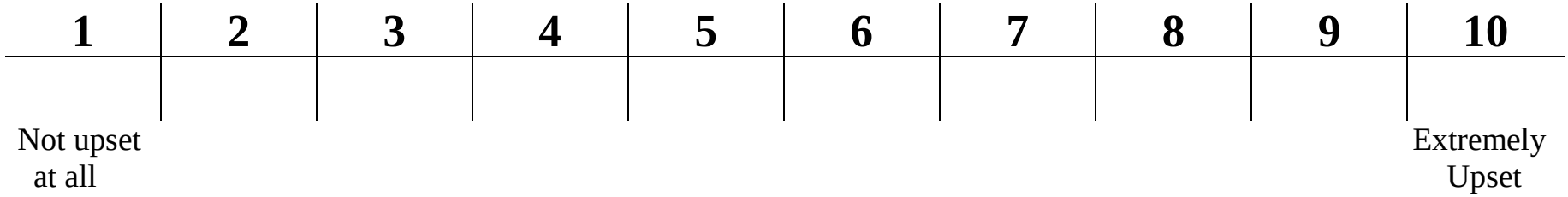
0
not tired
at all
1
a little
tired
2
3
getting more
tired
4
5
tired
6
7
really
tired
8
9
very, very
tired
10

A4.6 Gut fullness and gastric discomfort anchored 10-point semantic differential scales

How Full Does your Stomach Feel?



How Upset Does your Stomach Feel?



Appendix 5: Research Papers Published from this Thesis Work

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